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SYSTOLIC AND DIASTOLIC BLOOD PRESSURE IN HEALTHY MEN

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Although the subject of arterial blood pressure has a long bibliography, most of the discussions are based on investigations which are comparatively limited in scope. Data have been collected and analyzed by various observers, and the persons examined have been of varying types,—university students, insurance policy holders or applicants, soldiers, obese or elderly persons, or patients at free clinics,—but usually only patients under a long period of observation have been given repeated examinations during several months. Clinicians have also studied and written of arterial hypertension in selected groups of patients after observing them over a period of years. But, as McWilliam(1) states, such data are insufficient for statistical purposes and classification. For this he believes it necessary to deal with repeated examinations of large numbers in order to avoid that source of error which obviously enters into single blood pressure determinations where the examinee's condition is upset by temporary causes, such as activity, digestive processes, posture, or nervous excitement during an application for insurance or during a visit to a physician or a clinic for professional advice. True blood pressure levels of healthy persons may best be determined by a thorough study of a small number of persons or by repeated examinations of a larger group whose members live under "carefully ascertained and controlled conditions."

Accordingly, the data for the study now submitted were obtained by making repeated examinations of the entire enlisted personnel of a regimental post. Such a group is not representative of the average population of an American city, and the inquiry is therefore not as

broad as it might be. It does, however, present figures for each of almost a thousand men, unselected in that every enlisted man in the garrison was included in the study, but selected, inasmuch as all are healthy men, physically fit to be in the military service. All these men lived under the same conditions in respect to food, work, shelter, and hours of duty during the period of examination. This fulfills the principle that any statistical group should include only individuals who have been subject to the same conditioning factors. Moreover, each man was examined several times, under identical conditions and surroundings. In spite of the fact that during the month of March there was a mild epidemic of influenza when about fifteen per cent of the command were admitted to hospital for an average stay of six days, no blood pressure determinations were made on any victim of the epidemic until some days after his return to duty. Two medical officers, Major Kirk P. Mason and the writer, made all the examinations themselves, and each man was examined by both. Climatic conditions did not vary as much as they ordinarily do during the months in which the examinations were made. The winter was mild, and March and April did not differ greatly from February. After the first week of May outdoor activities occupied the men, and it became noticeable that they preferred to go elsewhere than to the hospital for another blood pressure examination. Most of the examinations were, therefore, made during a period when the weather was cold and it was necessary to remain indoors most of the time.

During the earlier weeks, when the men were being examined for the first time, there was frequently detected a certain nervousness or apprehension as to what it was all about, but this disappeared and they were soon more than willing to be examined and became interested in the readings. Some actually went so far as to bet what their blood pressure would be. Others often came for a blood pressure reading when not specifically sent for. For the ability to complete his program, the writer is much indebted to this spirit of coöperation among the men, as well as to that of their officers, and to the excellent state of the discipline of the command.

It would be interesting and instructive could a further study, over the next ten years, be made of the men from whom the data herein discussed were obtained, and another report made, but in the meantime this analysis of the available figures is presented because of the comparative rarity of such material.

EXPLANATION OF TERMS

The normal limits of arterial blood pressure in healthy adults are not fixed, but it is generally agreed that a diastolic index of 90 mm. or more is above normal, and that a systolic pressure of 140 mm. or more up to the age of 40 years, and of 150 mm. or more thereafter demonstrate abnormally great arterial blood pressure. No valid reasons are given for a change of ten millimeters in normal systolic pressure at 40 years of age; therefore in this study a systolic pressure of 140 mm. or more and a diastolic of 90 mm. or more are regarded as above normal. Some persons in that category are borderline cases, as are many with systolic or diastolic pressure just below 140 or 90 mm. respectively. Some of the borderline cases may well be hyperpietics or even incipient hypertensives with pathological lesions, although the artificial boundary line bars some of them from the abnormal group.

Friedlander(2) accepts the dictum of the majority of writers that a systolic pressure under 110 mm. is below normal. McWilliam(1) considers the lower limit of the systolic pressure to be 100 mm., and of the diastolic, 60 mm. In this study, 110 mm. and 65 mm. are the respective figures for the lower limit of the normal zone.

In order to avoid confusion it will be necessary to bear in mind just what is meant in this study by the terms *examination* and *reading*. Each visit to the hospital for a blood pressure determination is called an examination. During each examination, several readings of both systolic and diastolic pressures were made.

After having collected, at different examinations, an array of blood pressure readings for each man, it was necessary to decide first, whether to take into consideration all of the readings, and second, whether to use the mean or the median as the arbitrary measure of a man's blood pressure. Some investigators have eliminated from consideration the first readings at each examination because nervousness or excitement would make them high. McWilliam (1) says that repetition of readings is necessary to correct disturbances in pressure due to such causes and that subsequent readings are decidedly lower until a constant level, the residual pressure, is reached. As will be shown subsequently, there was such a factor in the present series, but it was not universal and any rule based on such a premise would exclude many of the higher readings and tend to give an incomplete picture. And, furthermore, it is not known that when a man's blood pressure fluctuates widely he may not be just as abnormal as when it remains moderately high. It was therefore decided to use all the recorded readings in deciding on a man's blood pressure level.

Generally the array of readings was a fairly long one, averaging over fourteen readings per man, and often moderately unsymmetrical in distribution. Because of the latter fact the use of the arithmetic mean seemed less rational than that of the median, which is the point on the scale on each side of which half the measures fall. The attempt to find some typical measure to point out the central tendency of an array often results in a fictitious statement of affairs, for in unsymmetrical arrays the mean, median, and mode are often widely separated. In this instance, in about twenty arrays, chosen at random, the mean and median were experimentally found to be very close together, and therefore the median of each array was

selected for statistical use in this study. This measure, then, represents the central tendency of each index of the arterial pressure of each man, and receives application as, respectively, the *median systolic* and the *median diastolic pressure.* The use of any average in arrays no longer than these is open to question unless there is a detailed study of the distribution; such will be made in a discussion of the range.

The array of readings in each examination being much shorter and more symmetrical, the mean of each such systolic and diastolic array was determined and is referred to as the *mean systolic* and the *mean diastolic pressure of each examination.*

Pulse pressure, although dependent on two variables and thus a less stable statistical measure, is worthy of some consideration. The difference between the median systolic and median diastolic pressures of each man is regarded as the man's *median pulse pressure.* The difference between the mean systolic and diastolic pressures at each examination is called the *mean pulse pressure of each examination.*

There is, then, for each man only one median systolic, diastolic, and pulse pressure, but there are several mean pressures, according to the number of examinations at which more than one reading was made.

The term *range* is used to denote the difference between each man's highest and lowest readings. Statistically, this figure is not of the greatest importance, but it is the most practicable and convenient way to study the distribution of the array of readings. Three ranges are discussed,—the *total range,* taken from the array of all the readings; the *range of the means,* which is the difference between the highest and lowest means; and the *range of the readings at each examination.*

The *coefficient of correlation* is a statistical measure which receives much attention in this study. The mass of data obtained during four months is a complex one and demands some yardstick to enable the mind to form a conception of the extent of the relationship between two given characteristics. Such a measure, even when significant, does not furnish proof of a relationship and is of value only so far as it agrees with sound logical analysis. The coefficient of correlation when used as it should be, without basing unjustified conclusions upon it, enables one to clarify a complex mass of figures; it expresses facts by numbers, thus making it possible to concentrate an extended experience into a quantity which can be easily compared with the experiences of others. The formula used in the computations is the well-known one, $r_{xy} = \frac{\Sigma xy}{N\sigma_x\sigma_y}$. The coefficient is always a decimal which must be between +1 and —1, — an ideal formula for the comparison of the connection between different pairs of characteristics. Perfect correlation (direct or inverse according to whether + or —) is represented by unity, and complete absence of correlation by zero. To be of any significance, the coefficient of correlation must be at least three or four times the standard deviation.

The *standard deviation* is a measure of the scattering of the figures in the distribution. It means first (to make a practical application of the definition) that if another regimental post were to be examined as this one was, the odds are 2.15 to 1 that the central figures then obtained would be within the limits of the respective standard deviations as computed in this study. It also means that 99.73 per cent of the means or medians obtained in a similar study of any other regimental post

would lie within the limits of three times the standard deviations found in this study. This measure is generally known as σ. A range of 6 σ usually includes 99 per cent or more of all the observations in the case of distributions of the symmetrical or moderately asymmetrical types.

The *coefficient of variation* expresses the standard deviation as a percentage of the mean. It is a constant, and differs from the standard deviation in that the latter measures degrees of variation in units, such as pounds, inches, millimeters of mercury, etc., while the coefficient of variation is a relative measure of variation which makes it possible to say whether men are more variable in, for instance, the systolic blood pressure than in the diastolic. (Pearl(3)). The formula is

$$\text{C of V} = \frac{100\sigma \text{ (distribution)}}{\text{Mean}}.$$

TECHNIC OF THE EXAMINATION

The men reported at the Station Hospital ordinarily in groups of about twenty. Two medical officers, the writer and another, working in two different rooms each took half of the men. As many as possible, practically all of them, sat while awaiting their turn. Quiet was maintained and the men actually rested. Mercurial manometers were used. Great care was always taken in the proper adjustment of the arm band, and in the standardizing of all conditions. Each man's pulse was counted before fastening on the arm band, and again just after reading the pressure. He was always in a comfortable sitting position while being examined.

As soon as the arm band was adjusted, it was ordinarily inflated to about 140 mm. and the first reading made during deflation. For men who registered a pressure higher than that it was of course necessary to inflate to a higher degree, but the principle was always the same,—to read during deflation from a point ten to fifteen millimeters above the actual pressure. Diastolic pressure was read at the beginning of the fourth phase, and not at the point of total disappearance of all sound. As soon as the diastolic pressure was read, the arm band was rapidly deflated and the readings recorded. After a moment's rest, inflation was produced to a pressure about ten millimeters higher than the previous systolic reading and the procedure repeated. There was no previously determined upon uniformity in the number of readings to be made; four happened to be the most common number. The purpose was to make enough readings to determine the point of stability of pressure.

During these numerous readings, a number of interesting observations were made by both of us.

1. The character of the sounds in different persons varied markedly.
2. The duration of the respective sound phases varied in different persons.
3. If the diastolic pressure is taken during inflation instead of deflation, it is higher. In other words, if one is not certain of the diastolic reading and desires to read it again without another systolic reading, it is necessary to inflate to a pressure about ten to fifteen millimeters above the expected reading, and then read while deflating.
4. In certain men, where the sounds were indistinct, the tactile method was used in conjunction with the auscultatory, and the latter reading was found to be ten to fifteen millimeters higher.

5. The proper rapidity of deflation varies somewhat with different individuals, in that for some of the younger men greater rapidity is necessary in order to distinguish the transition from the third to the fourth phase. But if the speed is increased too much, a reading higher by five to ten millimeters is obtained.

6. Variations in a man's blood pressure were found to be so rapid that although pressures were always read alternately,—systolic, diastolic,—it was evident that for men whose pressures varied considerably, a diastolic reading often presaged the next succeeding systolic reading. Thus, one blood pressure reading of two indices during one inflation does not always give a true picture.

7. Some of the examinees had irregular heart action, more noticeable at some examinations than at others. When most irregular, the blood pressure was difficult to interpret. After a missed beat, the next one is more forceful and the reading is high. The succeeding beats will then probably be lesser contractions with an abnormally low pressure.

8. Occasionally, pressure readings were taken from each arm during an examination, when there was any doubt as to an interpretation. Findings differed, but as the readings varied markedly in the one arm, it would be impossible to say whether pressure in both arms differed unless estimations were made simultaneously.

9. In a very few instances, after the first or second reading during an examination, the sounds seemed to fade away after the systolic index was read, and it was impossible to detect the changes in sound as the succeeding phases occurred. McWilliam(1) has described this phenomenon. He states that in a certain number of subjects there is, after prolonged compression of the arm, an enfeeblement or disappearance in the neighborhood of the systolic level of all sounds below the upper region of sound. This may also occur when the actual blood pressure is unchanged. Also, he states that there may be a cutting down of the systolic index with a rise in the diastolic as a result of the compression which involves marked turgescence distally to the compressing armlet. Conditions resembling these just described were encountered very rarely, because compression was never prolonged and whenever there was any suspicion of inaccuracy in the auscultatory reading it was checked with a tactile systolic reading and by readings on the other arm. McWilliam also thinks that repeated or continued compression may cause a decided rise in pressure. A rise due to this cause would be difficult to distinguish from one brought about by reflex action on a nervous patient. As will be shown, comparatively few of the men examined, whose blood pressure varied during the examination, reacted in the same manner at successive examinations.

It has also been stated that repeated inflations of the armlet lower the blood pressure in the succeeding readings because the prolonged pressure destroys the elasticity of the artery. This theory does not find application in the current series because pressure was not applied sufficiently long to accomplish that result, and because, if it were basically true, in examinations such as those recorded here, there would be a tendency for each man's readings to have the same trend at each examination. As will be shown, this is not the case.

NATURE OF INCREASED ARTERIAL TENSION

Wiggers' conception of high blood pressure is that it is a compensatory reaction designed to restore a normal blood supply to the tissues of the body. When the pressure is very high there is danger of rupture of a blood vessel or of decompensation of the heart. Clinical evidence supports Clifford Allbutt in his idea that hyperpiesis is the cause rather than the result of the characteristic pathology of acute vascular disease. Friedlander's contention that hypotension is not a disease but that it is often a manifestation of a diseased bodily state, one of several symptoms, may well be applied to hyperpiesis. Major describes hyperpiesis as a "disease of theories" and believes that the control of this condition is one of the outstanding challenges of today. As a contribution to the ultimate successful acceptance of that challenge, this study is submitted.

NUMBER OF MEN EXAMINED

Nine hundred and seventy-six men, comprising practically the entire enlisted personnel of a regimental post, were examined between January 20 and May 20, 1932. During that period the mean strength of the garrison fluctuated from week to week between a low of 904 and a high of 942. It is thus evident that very few, if any, of the men present for duty at any time during that period were omitted, thus making this survey a complete one so far as examinees are concerned.

TABLE 1

Frequency Distribution of the Number of Blood Pressure Examinations per Man

NO. OF EXAMS. PER MAN	NO. OF MEN	TOTAL EXAMS.
1	18	18
2	15	30
3	26	78
4	729	2916
5	140	700
6	32	192
7	10	70
8	2	16
9	1	9
10	1	10
11	1	11
16	1	16
	976	4066

NUMBER OF EXAMINATIONS PER MAN

Table 1 shows that of the 976 men examined, 729 had four examinations each, and 869 had either four or five. The mean number of examinations per man is 4.73. There were 4066 examinations altogether. Most of these were made in the early afternoon but all hours of the day saw the manometers in use, for it was necessary to utilize every opportunity to do this work, since each examination required about five minutes and this investigation was carried on in addition to the routine work of the hospital.

TABLE 2

Frequency Distribution of the Number of Readings per Examination

READINGS PER EXAM.	NO. OF EXAMS.	TOTAL READINGS
1	707	707
2	438	876
3	652	1956
4	1670	6680
5	429	2145
6	138	828
7	17	118
8	13	104
9	2	18
	4066	13,433

TABLE 3

Frequency Distribution of the Total Number of Blood Pressure Readings per Man

TOTAL READINGS PER MAN	NO. OF MEN
1 to 5	33
6 to 10	108
11 to 15	558
16 to 20	231
21 to 25	37
26 to 30	5
31 to 35	4
	976

NUMBER OF READINGS PER EXAMINATION

In Table 2 it is shown that there was a grand total of 13,433 readings of each index of arterial blood pressure, and that almost half of the examinations consisted of four readings each.

NUMBER OF READINGS PER MAN

Considerably more than half of the 976 men had, each, 11 to 15 readings during the four months. (Table 3). The mean number per man is 14.4.

TABLE 4

Frequency Distribution of Height

HEIGHT *inches*	FREQUENCY	HEIGHT *inches*	FREQUENCY	HEIGHT *inches*	FREQUENCY
61	3	67	160	73	11
62	13	68	126	74	3
63	42	69	105	75	2
64	89	70	77	76	1
65	133	71	32	Total	976
66	155	72	24		

HEIGHT DISTRIBUTION

Table 4 shows the height distribution, which has a range of 14 inches between the tallest and the shortest group. The mean height is $67.49 \pm .08$ inches. The standard deviation of the distribution is 2.4 inches, and the coefficient of variation is 3.5,—denoting a very small variation. The median height is 67.495 and the mode is 67+. Thus, so far as their heights are concerned, this garrison happened to be a representative group of soldiers for a blood pressure study.

WEIGHT DISTRIBUTION

In order to plot a frequency distribution of the weights of the men, it was first necessary to reduce the actual figures to a common denominator by taking some table of normal weights based on height and age as a standard, and then expressing relative weight by per cent above and below normal. The table of weights used is that given in AR 40—100,

11, December 3, 1931. The grouping by per cent above and below normal is the same as the "build groups" of the Medico-Actuarial Mortality Investigation. The frequency distribution is shown in Table 8. The mean weight is 2.92 ± .34 per cent above normal. The standard deviation of the distribution is 10.7 per cent, a considerably greater dispersion than in the case of the heights.

AGE DISTRIBUTION

The age distribution, as anticipated, presents an entirely different picture, (Table 9). The enlisted man in the military service is a fairly young man; his mean age is 28.75 ± .25 years. The standard deviation is 7.89 years and the coefficient of variation, 28. The mode is in the 20 to 24 group, and the median is 27.9 years.

LENGTH OF MILITARY SERVICE

The frequency distribution for the length of military service (Table 5) somewhat resembles that for age. The mean length of service is

TABLE 5

Frequency Distribution of Length of Military Service

SERVICE *years*	FREQUENCY	SERVICE *years*	FREQUENCY	SERVICE *years*	FREQUENCY
0-2	382	12-14	72	24-26	13
3-5	212	15-17	43	27-29	10
6-8	137	18-20	24	Total	976
9-11	67	21-23	16		

6.54 ± .2 years. The average soldier in this post is, then beginning his third enlistment period. Almost half of his service (3.1 ± .1 years) has been spent at his present station.

CHIEF CHARACTERISTICS OF THE GROUP WHOSE ARTERIAL BLOOD PRESSURE IS UNDER ANALYSIS

The group is made up of young, healthy adults, whose mean age is 28.75 years, mean height 67.5 inches, mean weight + 2.9 per cent, mean total service 6.5 years, and mean service at present station 3.1 years.

SYSTOLIC BLOOD PRESSURE

Table 11 shows the frequency distribution of the median systolic pressure of each man. The mean is 128 ± .38 mm. The mode is in this group and the median of the array of medians is 126.78 mm. The coefficient of variation is 9, exactly the same as that found by Symonds(4).

About nine-tenths of the median systolic pressures are under 140 mm. The arithmetic mean of the mean systolic pressures at each of the 4066 examinations was found to be 129.1 ± .02 mm. as compared with 128 ± .38 mm. for the mean of the median systolic pressures. The standard deviation for the former is 14 mm., and for the latter 12 mm.

Those subjects having median systolic pressures of 140 mm. or more are further analyzed in age and weight groups respectively, in Tables 6, 8 and 9. It is striking that 89 per cent of them are under the age of

TABLE 6

Relative Ages and Weight of Cases of Hyperpiesis and Hypotension

	MEAN AGE	S. D. OF AGE	MEAN WT.	S. D. OF WT.
Entire Group	28.8 ± .2	7.9	+2.9 ± .3%	10.7
Syst. over 140	29.6 ± .8	9.4	+5.4 ± 1. %	11.2
Syst. under 110.....	23.6 ± 1.3	7.0	−1 ± 1.6%	9.1
Diast. over 90	33.4 ± .8	9.0	+7.4 ± 1.2%	13.2
Diast. under 65	25.7 ± 1.	6.5	− .4 ± 1.4%	9.5

TABLE 7

Range of Systolic and Diastolic Pressures

RANGE	SYSTOLIC		DIASTOLIC	
	Mean	S. D.	Mean	S. D.
Total	23.6 ± .3	9.4	18 ± .2	6.5
Each Exam.	7.6 ± .09	5.1	5.7 ± .07	4.
Means	17.1 ± .3	8.5	13.2 ± .2	6.1

40 years. The mean age of the man whose median systolic pressure is 140 mm. or more is 29.6 ± .78 years. The mean age of the entire group is 28.75 ± .25 years; therefore it is not at all improbable that some other random sample of a thousand soldiers might show that those having a median systolic pressure of 140 mm. or more are younger than the entire group.

TABLE 8

Systolic and Diastolic Pressure in Relation to Weight

WEIGHTS IN PER CENT BELOW AND ABOVE NORMAL	FREQUENCY	MEDIAN SYSTOLIC PRESSURE						MEDIAN DIASTOLIC PRESSURE					
		Above 140		140-110		Under 110		Above 90		90-65		Under 65	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
—25 to —34%	2	0	...	2	.2	0	...	0	...	2	.2	0	...
—15 to —24%	17	0	...	16	2.	1	3.3	1	.9	14	1.7	2	4.5
— 5 to —14%	196	24	17.8	162	20.	10	33.3	20	17.2	163	20.	13	30.
Normal	408	45	33.7	352	43.3	11	36.7	33	28.4	359	44.	16	36.
+ 5 to +14%	246	43	32.1	196	24.1	7	23.4	31	26.7	204	25.1	11	25.
+15 to +24%	82	16	12.	65	8.	1	3.3	21	18.1	59	7.2	2	4.5
+25 to +34%	16	4	3.	12	1.5	0	...	6	5.2	10	1.2	0	...
+35 to +44%	8	1	.7	7	.9	0	...	3	2.6	5	.6	0	...
+45 to +54%	1	1	.7	0	...	0	...	1	.9	0	...	0	...
Totals	976	134	100.	812	100.	30	100.	116	100.	816	100.	44	100.

TABLE 9

Systolic and Diastolic Pressure in Relation to Age

AGES	FREQUENCY	MEDIAN SYSTOLIC PRESSURE						MEDIAN DIASTOLIC PRESSURE					
		Above 140		140-110		Below 110		Above 90		90-65		Below 65	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Under 20	46	9	6.7	35	4.3	2	6.7	2	1.7	39	4.8	5	11.3
20 to 24	350	45	33.6	293	36.1	12	40.	22	19.	309	37.9	19	43.2
25 to 29	249	27	20.1	217	26.7	5	16.6	20	17.2	215	26.3	14	31.8
30 to 34	148	21	15.7	121	14.9	6	20.	27	23.3	118	14.5	3	6.8
35 to 39	88	18	13.4	68	8.4	2	6.7	21	18.1	66	8.1	1	2.3
40 to 44	43	3	2.2	37	4.6	3	10.	10	8.6	32	3.9	1	2.3
45 to 49	35	5	3.7	30	3.7	0	...	8	7.	27	3.3	0	...
50 to 54	12	4	3.	8	1.	0	...	3	2.6	8	1.	1	2.3
55 to 59	3	1	.8	2	.2	0	...	2	1.7	1	.1	0	...
60 to 64	2	1	.8	1	.1	0	...	1	.8	1	.1	0	...
Totals	976	134	100.	812	100.	30	100.	116	100.	816	100.	44	100.

Over half of those having median systolic pressures of 140 mm. or more are either in the normal weight group or are underweight. Thirty-two per cent are from five to fourteen per cent overweight, and the mean weight of the man who has a median systolic pressure of 140 mm. or more is + 5.4± .96 per cent. Since the mean weight of all the men is + 2.9 ± .34 per cent, there is seen to be some tendency for men who are overweight to have a higher systolic pressure. The difference between these figures is large enough to make the chances considerably less than even that in any other random sample those having a systolic pressure over 140 mm. would have a lesser mean weight than the entire group. There are 36 men of greater age than 40 years who are more than five per cent overweight. The mean systolic pressure of the group is 133.9 ± 2.08 mm., slightly higher than the mean of the entire group. Nine of the 36 (25%) have systolic pressures over 140 mm. These figures do not confirm those of The Actuarial Society of America which avers that two-thirds of all individuals over forty years of age who are ten pounds or more overweight show a definite elevation of blood pressure.

In Tables 8 and 9 those with median systolic pressures under 110 mm. are shown in per cent distributions according to age and weight. Men with hypotension are considerably less in number than those with hyperpiesis. The mean age and weight of this group are both less than the respective averages of the entire group. (Table 6).

Tables 11 and 12 show the distribution, in age and weight groups respectively, of the median systolic pressures.

TABLE 10

Mean Systolic and Diastolic Blood Pressures for Each Age Group

AGES	MEAN BLOOD PRESSURES	
	Systolic	Diastolic
Under 20	127.4 ± 1.8	76.5 ± 1.3
20 to 24	127.6 ± .6	77.1 ± .4
25 to 29	127.5 ± .7	79.2 ± .6
30 to 34	128.3 ± 1.	82.4 ± .8
35 to 39	129.4 ± 1.6	83.2 ± 1.2
40 to 44	124.5 ± 1.7	83.8 ± 1.3
45 to 49	129.9 ± 2.0	85.9 ± 1.5
50 to 54	135. ± 3.7	84.2 ± 2.5
55 to 59	141.7 ± 6.0	95. ± 4.7
60 to 64	150. ± 10.7	90. ± 5.0

Table 10 shows the mean systolic and diastolic pressure of each age group. It is worthy of note that the age group 40 to 44 has the lowest mean systolic pressure of all the groups, and that only two age groups, 55 to 59 and 60 to 64, have a mean systolic pressure of over 140 mm., and that there are only three and two, respectively, in those groups.

TABLE 11

Correlation Between Median Systolic Blood Pressure and Age

MEDIAN SYSTOLIC PRESSURES	AGES										Totals
	Under 20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	
100 to 109	2	12	5	6	2	3	..	..	..	..	30
110 to 119	11	81	57	32	25	13	6	2	..	..	227
120 to 129	18	122	97	47	25	15	15	2	..	..	341
130 to 139	6	90	63	42	18	9	9	4	2	1	244
140 to 149	8	31	18	13	11	1	3	2	..	..	87
150 to 159	..	12	6	7	3	2	1	2	1	..	34
160 to 169	1	1	2	1	1	..	..	..	..	1	7
170 to 179	..	1	1	..	3	..	1	..	..	..	6
Totals	46	350	249	148	88	43	35	12	3	2	976

TABLE 12

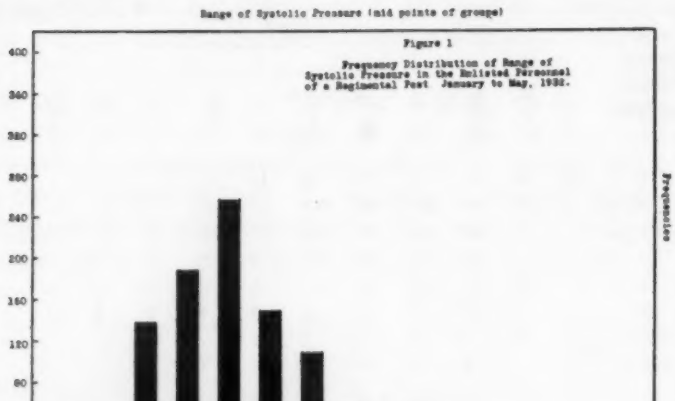
Correlation Between Median Systolic Blood Pressure and Weight Expressed in Per Cent Above or Below Normal

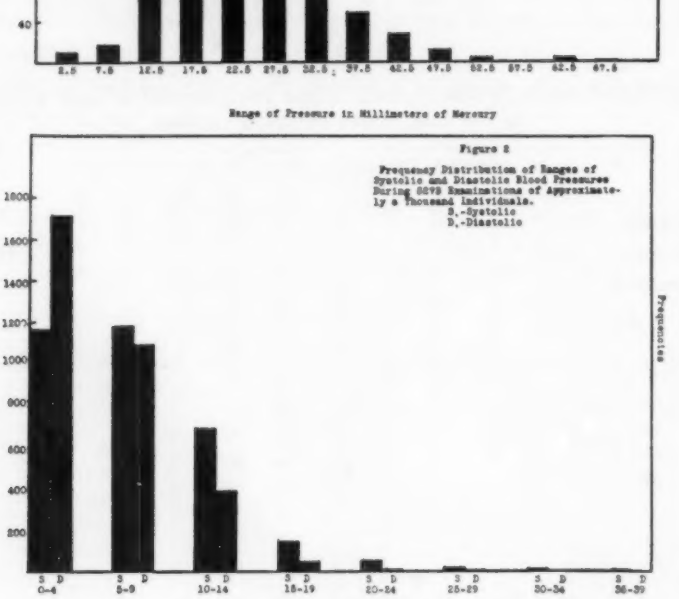
MEDIAN SYSTOLIC PRESSURE	WEIGHT, PER CENT ABOVE OR BELOW NORMAL									Totals
	—25% to —34%	—15% to —24%	— 5% to —14%	Normal	+ 5% to +14%	+15% to +24%	+25% to +34%	+35% to +44%	+45% to +54%	
100 to 109	..	1	10	11	7	1	..	..	..	30
110 to 119	1	6	57	101	43	16	1	2	..	227
120 to 129	..	6	71	157	79	20	6	2	..	341
130 to 139	1	4	34	94	74	29	5	3	..	244
140 to 149	..	..	15	30	30	8	2	1	1	87
150 to 159	..	..	5	11	11	6	1	..	..	34
160 to 169	..	..	2	3	1	1	..	..	..	7
170 to 179	..	..	2	1	1	1	1	..	..	6
Totals	2	17	196	408	246	82	16	8	1	976

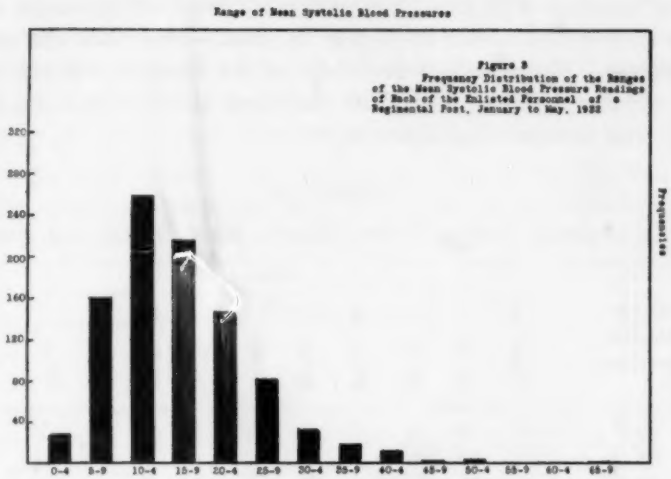
RANGE OF SYSTOLIC PRESSURE

The range of systolic pressure was studied from three angles:

1. Total range of all the systolic indices recorded for each man.
2. Range of systolic indices at each examination which consisted of more than two readings.
3. Range of each man's mean systolic indices (where he was examined more than once).







The respective frequency distributions for the three ranges are shown in Figures 1, 2, and 3. The means and standard deviations are given in Table 7. Such wide variations were unexpected when this investigation was instituted. The original intention had been to make one or two readings during each examination, but when wide fluctuations were occasionally observed, the scope of the examinations was enlarged, although not until about seven hundred examinations with only one reading each had been made.

The means of the three types of range studied have comparatively low standard deviations, as have the distributions, because the figures are based on over 3350 examinations. For the total range and for the range of the means, the figures are individual, but the range at each examination includes in one array all the examinations. The respective means of the three types of range are comparable; the trend toward a marked variation in systolic pressures at each examination as well as toward a similar fluctuation in the mean systolic pressures of the examinations conducted at intervals is striking.

DIASTOLIC BLOOD PRESSURE

The frequency distribution of the median diastolic pressures, per man, is shown in Table 13. The mean of the median diastolic pressures is $79.7 \pm .3$ mm. The mode is in the same group, and the median of the

array of medians is 79 mm. The arithmetic mean of the means of each of the 4066 examinations is 79.9 ± .16 mm.,—very near the mean of the medians. The standard deviations of the distributions are, respectively, 9.4 mm. and 10.4 mm. The coefficient of variation is 12, slightly greater than Symonds'(4) figure of 10.

TABLE 13

Correlation Between Median Diastolic Blood Pressure and Age

MEDIAN DIASTOLIC PRESSURES	AGES										Totals
	Under 20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	
50 to 59	1	1	3	1	1	..	..	..	..	..	7
60 to 69	7	60	29	9	7	2	..	1	..	..	115
70 to 79	25	177	101	52	28	12	9	2	..	..	406
80 to 89	11	90	96	59	31	19	18	6	1	1	332
90 to 99	1	21	16	20	14	9	4	3	1	1	90
100 to 109	1	..	4	7	6	1	4	..	1	..	24
110 to 119	..	1	..	..	1	..	..	..	..	..	2
Total	46	350	249	148	88	43	35	12	3	2	976

TABLE 14

Correlation Between Median Diastolic Blood Pressure and Weight Expressed in Per Cent Above or Below Normal

MEDIAN DIASTOLIC PRESSURE	WEIGHT, PER CENT ABOVE OR BELOW NORMAL									Totals
	—34% to —25%	—24% to —15%	—14% to — 5%	Normal	+ 5% to +14%	+15% to +24%	+25% to +34%	+35% to +44%	+45% to +54%	
50 to 59	..	..	1	3	3	..	..	..	..	7
60 to 69	..	3	35	50	20	7	..	..	..	115
70 to 79	2	8	84	188	99	20	4	1	..	406
80 to 89	..	5	56	134	93	34	6	4	..	332
90 to 99	..	1	19	26	23	17	2	2	..	90
100 to 109	..	..	1	6	8	4	3	1	1	24
110 to 119	..	..	..	1	..	..	1	..	..	2
Totals	2	17	196	408	246	82	16	8	1	976

In Tables 6, 8 and 9, those having median diastolic pressures of over 90 mm. are analyzed in respect to age and weight. Increased diastolic pressure is found to occur more often in older and in heavier individuals than is increased systolic pressure. The difference between the mean age and weight of the man with a diastolic pressure of over 90 mm. and the corresponding means of the entire group is so great that, unlike the case with systolic hyperpiesis, there is no statistical possibility that a random sample could be found where the average age or weight of the

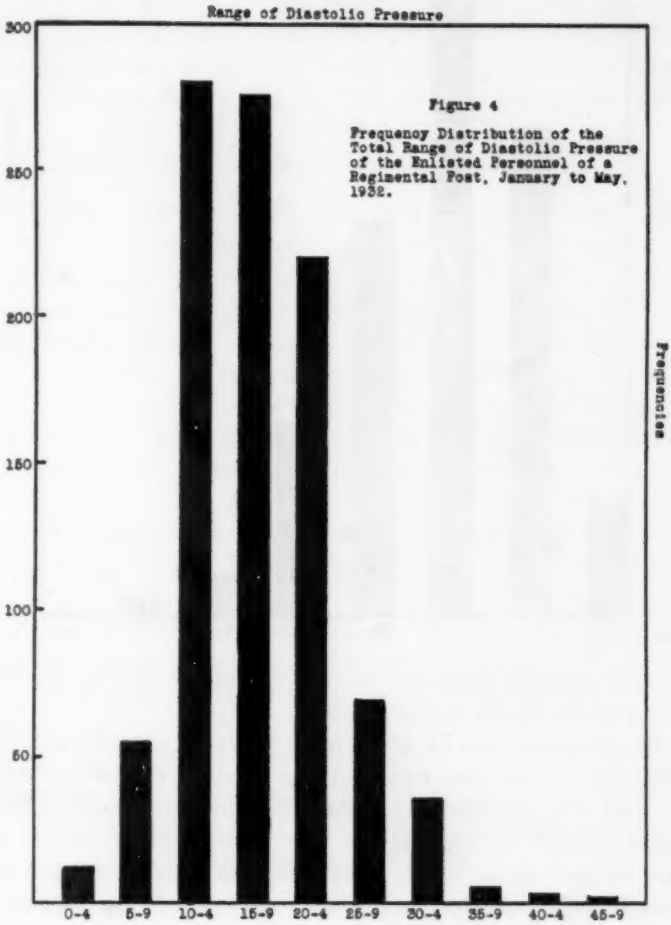


Figure 4

Frequency Distribution of the Total Range of Diastolic Pressure of the Enlisted Personnel of a Regimental Post, January to May, 1932.

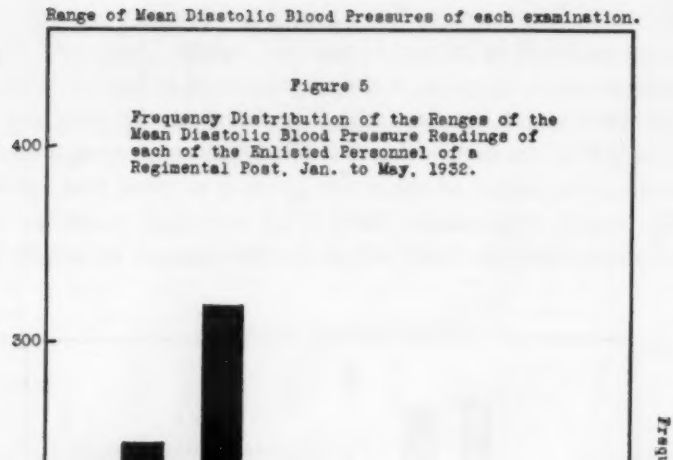


Figure 5

Frequency Distribution of the Ranges of the Mean Diastolic Blood Pressure Readings of each of the Enlisted Personnel of a Regimental Post, Jan. to May, 1932.

men having diastolic pressures of over 90 mm. would be less than the similar averages of the entire group.

In the group of men of 40 or more years of age who are over five per cent overweight, the mean of the median diastolic pressures is 89.7 ± 1.45 mm., considerably higher than the corresponding figure for the entire group. Forty-four per cent of this group have a diastolic pressure of 90 mm. or more. There is thus a much greater tendency for those who are overweight and over 40 years of age to have a high diastolic index than a high systolic.

Tables 8 and 9 show the per cent distribution by weight and age groups of the men with median diastolic pressures under 65 mm. The mean weight and age of this group are less than the corresponding means of the entire group but greater than those of the men with systolic hypotension. (Table 6). It seems safe to infer that in the entire group the diastolic index shows a greater degree of positive correlation with weight and age than the systolic, but that the opposite is the case in the hypotension group.

Tables 13 and 14 show the distribution of the median diastolic pressures in age and weight groups, respectively. In Table 10 the mean diastolic index for each age group is shown; there is apparently a more definite trend toward an increase in the diastolic index with increasing age and weight than is the case with the trend of the systolic index.

RANGE OF DIASTOLIC PRESSURE

The range of diastolic pressure was investigated in the same manner as was that of the systolic index. The various ranges are shown in Figures 2, 4, and 5, and in Table 7. The mean diastolic ranges with their standard deviations are all proportionately less than the corresponding systolic ranges. During the process of making the blood pressure determinations there was at first some thought of the possibility of the personal elements being the cause for fluctuations in the diastolic index. It was scarcely conceivable that such could be the case in the readings of the systolic pressure, but the diastolic reading is more difficult to make. When, however, in computations, the figures tallied so closely and so logically with those for systolic variation, it seemed clear that the personal element was negligible. The standard deviations of the means and of the distributions are even smaller than the corresponding figures for the systolic ranges. There is as proportionately great a trend toward fluctuation of diastolic pressures from time to time and at any given examination as exists in the case of systolic pressure.

WHICH EXAMINATION OF A MAN, THE FIRST OR A SUCCEEDING ONE, GAVE THE HIGHEST AND WHICH THE LOWEST MEAN SYSTOLIC PRESSURES?

There were 729 men who received four examinations each, and 140 who received five each. The other hundred men were examined once,

twice, three times, or more than five times each, respectively; the groupings are smaller and are therefore of much less value statistically. If the laws of chance alone operated, it would be expected that the high mean systolic pressure would be approximately equally distributed among each man's successive examinations. In Table 15 it is shown

TABLE 15

Men Who Received Four Examinations
Relative Frequency With Which the Highest Mean Systolic Pressure of a Man was Observed at His 1st, 2nd, 3rd or 4th Examination

HIGHEST MEAN SYSTOLIC PRESSURE							
At 1st exam.		At 2nd exam.		At 3rd exam.		At 4th exam.	
No.	%	No.	%	No.	%	No.	%
316	43.2	194	26.6	124	17.	96	13.2

TABLE 16

Men Who Received Five Examinations
Relative Frequency With Which the Highest Mean Systolic Pressure of a Man was Observed at His 1st, 2nd, 3rd, 4th or 5th Examination

HIGHEST MEAN SYSTOLIC PRESSURE									
At 1st exam.		At 2nd exam.		At 3rd exam.		At 4th exam.		At 5th exam.	
No.	%	No.	%	No.	%	No.	%	No.	%
56	39.7	30	21.3	24	17.1	20	14.2	11	7.7

TABLE 17

Men Who Received Four Examinations
Relative Frequency With Which the Lowest Mean Systolic Pressure of a Man was Observed at His 1st, 2nd, 3rd or 4th Examination

LOWEST MEAN SYSTOLIC PRESSURE							
At 1st exam.		At 2nd exam.		At 3rd exam.		At 4th exam.	
No.	%	No.	%	No.	%	No.	%
103	14.2	159	21.9	198	27.2	268	36.7

TABLE 18

Men Who Received Five Examinations
Relative Frequency With Which the Lowest Mean Systolic Pressure of a Man was Observed at His 1st, 2nd, 3rd, 4th or 5th Examination

LOWEST MEAN SYSTOLIC PRESSURE									
At 1st exam.		At 2nd exam.		At 3rd exam.		At 4th exam.		At 5th exam.	
No.	%	No.	%	No.	%	No.	%	No.	%
10	7.	30	21.1	27	19.	28	19.7	47	33.2

that for 43 per cent of the men who were examined four times, the highest mean systolic pressure was that of the first examination. It is true that many of the first examinations had only one reading each, but there were nearly always more readings at succeeding examinations. If this had much effect on the distribution, the high should be equally scattered among the other examinations. But this is not the case. The second, third, and fourth examinations have respectively 27, 17, and 13 per cent of the high means. This seems to indicate that after the first examination the subject was not so nervous or apprehensive as he was at first when he had no idea why he was being sent to the hospital, and that his perturbation continued to decrease as he became more and more familiar with the process. During the four months of examinations there were repeated instances which demonstrated the influence of the emotions in raising the systolic pressure.

Table 16 shows similar data for the 140 men who had five examinations each. There is the same gradual decrease in the proportion of high mean systolic pressures from the first to the fifth examination.

Strangely enough, each man's lowest mean systolic pressure also occurred in an unequal distribution, but in exactly the reverse of the order in which the highest mean pressures were found to occur. In the series whose members had five examinations each, the same relative order of occurrence of the lowest mean pressures is found, but the difference is marked only between the first and fifth examinations. The second, third, and fourth examinations have practically equal percentages. (Tables 17 and 18).

RISE OR FALL IN SYSTOLIC PRESSURE DURING AN EXAMINATION

Each examination of two or more readings was studied to determine the trend in the systolic pressure during that examination,—whether up,

down, or unchanged. The data thus collected take into consideration only the first and last readings at each examination. Furthermore, a difference of more than two millimeters between those readings was required before a change either up or down was recorded. Frequently during "No Change" examinations there was an interim fluctuation of five to ten millimeters. No plan having been pre-arranged, the actual number of the readings taken at each examination was largely dependent

TABLE 19

Change in Systolic Pressure in the Course of an Examination in Relation to the Number of Readings at that Examination

READINGS	CHANGE IN SYSTOLIC PRESSURE						TOTAL
	Up		Down		None		
	No.	%	No.	%	No.	%	No.
2	20	4.7	188	44.3	216	51.	424
3	22	3.3	395	60.	243	36.7	660
4	124	7.4	1096	65.5	454	27.1	1674
5	31	7.3	286	69.	98	23.7	415
6	7	5.2	101	74.3	28	20.5	136
7	0	...	14	66.7	7	33.3	21
8	3	23.1	8	61.5	2	15.4	13
9	0	...	2	100.	0	...	2
Totals	207	6.2	2090	62.5	1048	31.3	3345

upon the time at the disposal of the examiner. Table 19 shows that "No Change" examinations decrease as the number of readings per examination increase, but that there is a marked tendency for the last reading to be lower than the first,—exactly the trend found in the case of variations of the mean systolic pressures at different examinations. The proportion of pressures which rise during an examination apparently is independent of the number of readings per examination.

In order to determine the existence among the men of any definite trend toward a similar reaction at each successive examination, the figures for the 862 men who had at least three examinations of two readings or more each are tabulated as follows:

1. Number of men whose systolic pressure always dropped at each examination 190
2. Number of men whose systolic pressure never fluctuated at any examination 22

3.	Number of men whose systolic pressure went up at each examination	0
4.	Number of men whose systolic pressure underwent all three changes: went up at one or more examinations, went down at others, and did not change at still others	93
5.	Number of men whose systolic pressure went up at some examinations, and down at others	57
6.	Number of men whose systolic pressure went up at some examinations, and did not change at others	24
7.	Number of men whose systolic pressure went down at some examinations, and did not change at others	476
	Total	862

Twenty per cent of the 862 men thus showed a consistent drop in pressure at each examination, but a still greater proportion of them showed a drop at some examinations but no change at others. If it were a fact that repeated compressions by an armlet reduce the elasticity of an artery and thus lower the reading, the seventh group above would not be so large, nor would so small a proportion be in the first group.

PULSE

At each examination the subject's pulse was counted after he had rested and just before the armlet of the sphygmomanometer was adjusted. It was again counted just after the last reading, before the man moved. A thirty second interval was used at the first count and a twenty at the second. The arithmetic mean pulse was computed for each examination and also for all the examinations given each man. The latter figure was considered the mean pulse of the individual, and was found to be $85.4 \pm .2$ beats per minute.

In order to determine whether there is a relationship between a rising pulse and a rising systolic pressure during an examination, the

TABLE 20

Changes in Pulse Rate as Associated with Changes in Systolic Pressure

PULSE	SYSTOLIC PRESSURE			TOTALS
	Rising	Falling	No Change	
Rising	27	301	134	462
Falling	37	563	269	869
No Change	137	1177	624	1938
Totals	201	2041	1027	3269

data shown in Table 20 were collected. A pulse rate was regarded as not changing unless it varied by more than four.

By using the method described by Edwin B. Wilson(5) for determining a condition of association or dissociation between two attributes or variables, the data in Table 20 were incorporated into four-fold association tables, "no change" being grouped in one case with falling pulse and systolic pressure, in the other case with rising. In the former case, since π, the chance of the pulse and systolic pressure both rising during an examination, practically equals p_1p_2, the products of the "chances" of each, the two attributes are independent, or unassociated. In the latter case, $\pi > p_1p_2$ ($.172 > .166$), but the difference is so small that although there is neither a satisfactory measure of the degree of association nor of its probable error, it seems likely that the two attributes are independent. "No Change" in pulse is, similarly, independent of "No Change" in systolic pressure.

PULSE PRESSURE

The pulse pressure, although of not so great moment, statistically, as either the systolic or diastolic pressure, was incorporated into this study for its possible interest. The median pulse pressure of each man is $49.3 \pm .35$ mm. with a standard deviation for the distribution of 10.95 mm. The coefficient of variation is 22, higher than Symonds'(4) figure of 17.7.

The range of the mean pulse pressures, that is, the difference between each man's highest and lowest mean, was found to be $17.7 \pm .29$ mm. This is slightly higher than the range of mean systolic pressures and over a third higher than the range of each man's mean diastolic pressures. (Table 7). The standard deviation of the distribution is 8.9 mm. and the coefficient of variation is 50.

CORRELATIONS

Age with Blood Pressure

The correlation coefficient for age and median systolic pressure in this series is $+ .11 \pm .03$. That for age and the median diastolic pressure is $+ .37 \pm .028$. The former is over three times the standard deviation, but is so near zero that correlation cannot be said to be present. On the other hand, the latter coefficient is thirteen times its

standard deviation and is therefore significant. Correlation is certainly present, although not marked, if we accept the following classification of correlation:

$r = .70$, very high
$r = .60$ to $.70$, high
$r = .40$ to $.60$, marked
$r = .20$ to $.40$, present

With advancing years, then, it appears that the diastolic index, but not the systolic, has a tendency to increase.

Weight with Blood Pressure

Each man's weight, computed in "build groups" was tabulated with, respectively, his median systolic and median diastolic pressures. As in the case of age, the correlation coefficient is greater with the diastolic pressure than with the systolic,— $+.36 \pm .03$ as compared with $+.22 \pm .032$. Both are in the correlation present class, one at the lower limit and the other at the upper. Both are significantly higher than their respective standard deviations. There is, then, a tendency for blood pressures, greater for the diastolic pressure than for the systolic, to increase with weight. If, as previously suggested, high blood pressure is a compensatory reaction, an increase in blood pressure is necessary as body weight increases in order to supply blood to the extra tissues. And if increased blood pressure is a cause of vascular as well as of other diseases, keeping one's weight within the limits of the normal range might prevent some of the degenerative diseases of later life.

Length of Service, with Blood Pressure

The correlation of blood pressure with length of military service might be expected to be almost the same as the similar correlation with age. But there is a difference. Both coefficients (systolic and diastolic) are much lower in the case of length of service than in the case of age. In fact, the correlation coefficient for length of service and systolic pressure is $-.012 \pm .03$ instead of $+.11 \pm .03$, the coefficient for age and systolic pressure. What slight significance attached to the latter figure is lost when length of service is substituted for age. The coefficient is actually negative, although less than its probable error. The coefficient for length of service and diastolic pressure is $+.17 \pm .03$, significant in terms of its standard deviation but not officially "present." Thus, un-

fortunately, the difference is not great enough really to justify the invention of a recruiting slogan urging one to "Re-enlist in the Army and lower your blood pressure."

Mean Systolic Pressure with Mean Diastolic Pressure

A high correlation between the mean systolic pressure at each examination and the corresponding diastolic index is to be expected. It was computed and found to be $+.6 \pm .01$.

Pulse with Blood Pressure

Correlation between the frequency of the pulse and the median systolic and diastolic pressures is present. Each is significant in that each coefficient is ten times its standard deviation, but the coefficients are not large, being $+.325 \pm .03$ for the systolic pressure and $+.295 \pm .03$ for the diastolic. In other words, both systolic and diastolic pressures tend to be higher, the higher the pulse. This is not contradictory to the findings when the four-fold table was used, for the latter pertained to mere rising or falling of the pulse during an examination and not to the actual pulse rate.

The correlation described in the preceding paragraph applies exclusively to individuals. The mean pulse at each of the 4066 examinations, when correlated with the mean systolic pressure at that examination, was found to have practically the same coefficient, $+.28 \pm .014$, except that it was twenty times its standard deviation instead of ten. Yet the corresponding correlation with the mean diastolic pressure was only $+.18 \pm .015$, as compared with that with the median diastolic for the individual, of $+.295 \pm .03$. No logical conclusion is apparent, largely because the difference is not sufficiently great to cause speculation about the reason, but it does suggest the question whether the relative fall in diastolic pressure results in part as a compensatory mechanism to counteract the effect of a high pulse rate.

Range of Systolic Pressure with Range of Diastolic Pressure

The correlation between the range of systolic pressure and that of the diastolic has practically the same coefficient whether the total range for each man or the range at each examination is concerned. In the former case it is $+.28 \pm .03$, and in the latter $+.37 \pm .016$. Thus the

conclusion is that to a slight extent, the higher the diastolic range is, the higher the systolic range will be, although there was no marked uniformity in an individual's respective ranges. At some examinations his systolic range might be high, at another his diastolic, and at still another they might be equal.

Median Blood Pressure with the Range of the Respective Mean Pressures

There is no correlation ($+.03 \pm .032$) between the range of the diastolic pressure of each man and his median diastolic pressure. The coefficient in the case of the range of each man's systolic pressure with his median systolic pressure is $+.18 \pm .03$, six times the standard deviation but only a barely noticeable correlation.

Range of Pressure with Number of Examinations

In order to determine any existing causal relationship between the range of the mean blood pressures of each man and the number of examinations each man was given, the correlation coefficients were computed and found to be $+.24 \pm .03$ for the range of mean diastolic pressures, and $+.23 \pm .03$ for the systolic range. There is, then, a just barely present positive correlation between the size of the fluctuation in both systolic and diastolic pressure from one examination to the other, and the number of examinations. This correlation is about eight times the standard deviation, but is small,—and may be interpreted to mean that, to a slight extent, the greater the number of examinations, the greater the variation. However, two or three examinations per man will probably show considerable variation, almost as much as a greater number.

Range of Pressure with Number of Readings

On the other hand, there is a more positive relationship between the range of blood pressure at each examination, and the number of readings at that examination. For the systolic range the coefficient is $+.34 \pm .015$, and for the diastolic, $+.45 \pm .014$. The latter may be designated as a marked correlation, and indicates that the diastolic pressure is likely to fluctuate more when the number of readings in an examination is increased than is the systolic. As compared with the previous correlation, there is then more probability of a man's blood pressure

fluctuating widely in the course of two or three examinations at different times than during an examination of only two or three readings.

The correlation coefficient for the total range of blood pressure of each man, with the total number of readings for that man, was lower than was the coefficient pertaining to the number of readings per examination. For the systolic range it is $+.31 \pm .03$, and for the diastolic $+.29 \pm .03$. This shows only a slightly greater correlation than that between the fluctuations of the means of the various examinations and the number of examinations given each man. It would appear, then, that in order to determine just how greatly a man's blood pressure may fluctuate, he should be examined at least three or four times, and given three to five readings at each examination.

Pulse Pressure with Systolic and Diastolic Pressure

Although there had been, for reasons already stated, some hesitancy before deciding to investigate the pulse pressure, the correlation coefficients brought out an interesting relationship. If the pulse pressure depends on the two variables equally, it should tend to increase as the systolic pressure increases and as the diastolic decreases, approximately equally. But the correlation coefficient of the pulse pressure with the median systolic pressure is $+.75 \pm .018$, very high, and over forty times its standard deviation, while that with the median diastolic is barely on the minus side of zero, and not even twice its standard deviation ($-.05 \pm .03$). The pulse pressure in the series studied fluctuates with the systolic pressure; the diastolic pressure does not fluctuate sufficiently to affect the pulse pressure. This agrees with the experience of Friedlander(2), who states that systolic pressure falls without much change in the diastolic, the pulse pressure being reduced in that manner.

This relationship is again shown in another pair of correlations, those between the range of the mean systolic and diastolic pressures of each man and the corresponding range of mean pulse pressures. The high correlation, $+.59 \pm .02$, is between the range of systolic pressure and that of the pulse pressure. In relation to the corresponding diastolic range, the coefficient is $+.29 \pm .03$,—not so marked a difference as before, but corroborative.

Pulse Pressure with Pulse Rate

According to McWilliam(1), pulse pressures of deficient amounts associated with high diastolic levels are of evil significance as indicating cardiac insufficiency, provided the low pulse pressure is not accounted for by acceleration of pulse rate. Friedlander(2) agrees that there is positive association between low pulse pressure and tachycardia, giving as the chief reason reduced cardiac power. A study of the accumulated data with special reference to these statements was made.

There were, in more than four thousand examinations, only seventy-three (69 men) where a pulse pressure of less than 35 mm. was associated with a diastolic pressure of over 90 mm. In only six of these seventy-three examinations was the pulse rate over 100 beats per minute, and this did not occur at more than one examination per man. This, according to the authorities quoted, would indicate cardiac insufficiency, but this condition was not apparent in the men examined, and, as it did not occur at all of the examinations of any one man, must have been a temporary condition, if it existed at all.

Correlation between the pulse pressure and pulse rate should be inverse to confirm the statements referred to, but the following coefficients of correlation were found:

1. Mean pulse of each man, with his median pulse pressure
$$r = +.11 \pm .013$$
2. Mean pulse at each examination with the mean pulse pressure at that examination
$$r = +.16 \pm .015$$

Both these coefficients are very small, but many times their respective standard deviations.

To investigate still further, four-fold association tables were made, with attribute I pulse pressure under 35 mm. and attribute II pulse rate over 100 beats per minute. The results indicated a negative association, or a dissociation, thus confirming the correlation coefficients, and denying the application of McWilliam's and Friedlander's statements to the thousand men studied.

Blood Pressure After Tour of Guard Duty

One hundred and ninety-two men were given one examination after a tour of duty as guard, at 9 A. M., after they had been on guard since

the previous noon. One hundred and twenty-four were each given two or more examinations after such tours. A tour of guard duty consists of two hours on guard, walking post, followed by four hours off. But during the latter period the men lie down to sleep with all their clothes on, in a more or less noisy room, with the lights being turned on and off frequently, so that unless a man is a heavy sleeper he gets but little rest. During the day preceding his guard tour he is busy polishing and cleaning, in preparation. The data are shown in Tables 21 and 22, and it is

TABLE 21

One Examination After Guard Tour
Frequency With Which the Mean Systolic Pressure After a Tour of Guard Duty was Higher, Intermediate, or Lower than at Least Three Others on Record for That Man

MEAN SYSTOLIC PRESSURE						
High		Intermediate		Low		Total
No.	%	No.	%	No.	%	
24	12.4	96	50.	72	37.6	192

TABLE 22

Two or More Examinations After Guard Tour
Frequency With Which the Mean Systolic Pressure After a Tour of Guard Duty was Intermediate or was Lower or Higher Than at Least Three Others on Record for That Man

	No.	%
Both Means High	2	1.7
Both Means Low	8	6.4
One High, One Low	19	15.3
One High, One or More Intermediate	10	8.1
One Low, One or More Intermediate	58	46.8
All or Both Intermediate	27	21.7
Totals	124	100.

evident that the tendency is for the mean systolic pressure to be lower after a tour of guard duty than during examinations at other times, and that the mean systolic pressure after the tour is more often the lowest for that man than it is the highest.

Blood Pressure and Use of Alcohol and Tobacco

Almost all the men were questioned about their use of alcoholic beverages and tobacco. They were assured that this personal information would not be made official, and the questions were asked them by a fellow soldier. Of 931, 353 stated that they are total abstainers, 535 that they drink moderately, and 43 that they are heavy drinkers. The mean of the median systolic pressures for the men of the group of abstainers was 126.5 ± .7, not significantly lower than the similar mean for the entire group, if one takes into consideration the higher standard deviations of the mean in the group of abstainers.

Only 122 of 933 men interrogated denied the use of tobacco. Almost half of the total, 461, smoke a package of cigarettes a day, and 140 exceed that amount daily. The mean of the median systolic pressures of the non-smokers is 128.77 ± 1.1, practically the same as the similar figure for the entire group.

TABLE 23

	MEAN	S. D. OF DISTRIBUTION
Age	28.8 ± .25	7.9
Total Service	6.5 ± .2	6.2
Weight	+2.9% ± .34%	10.6
Height	67.49 ± .08	2.4
Median Systolic	128. ± .34	12.
Mean Systolic Each Exam.	129.1 ± .02	14.
Median Diastolic	79.7 ± .3	9.4
Mean Diastolic Each Exam.	79.9 ± .015	10.7
Median Pulse Pressure	49.3 ± .35	11.
Mean Pulse	85.4 ± .2	10.
No. of Exams. per Man	4.7 ± .027	.84
Total Readings per Man	14.4 ± .13	4.1
Range of the Mean Systolic Pressure Readings of Each Man	17.1 ± .3	8.5
Range of the Mean Diastolic Readings of Each Man	13.2 ± .2	6.2
Total Range of Systolic Pressure, of all Readings, all Exams., Each Man	23.6 ± .3	9.4
Total Range of Diastolic Pressure, of all Readings, all Exams., Each Man	18. ± .2	6.5
Range of Systolic Pressure, Each Exam.	7.6 ± .09	5.1
Range of Diastolic Pressure, Each Exam.	5.7 ± .07	4.
Range of Mean Pulse Pressures of Each Man	17.7 ± .29	8.9
Median Systolic Pressure of those totally Abstaining from the Use of Alcoholic Beverages	126.5 ± .7	11.1
Median Systolic Pressure of those totally Abstaining from the Use of Tobacco	128.77 ± 1.1	12.1

TABLE 24

Blood Pressure Correlations Found During the Repeated Examinations of 976 Soldiers Between January 20 and May 20, 1932

Age and Median Systolic Blood Pressure	+.11 ± .03
Age and Median Diastolic Blood Pressure	+.37 ± .028
Per Cent above or below Normal Weight and Median Systolic Blood Pressure	+.22 ± .03
Per Cent above or below Normal Weight and Median Diastolic Blood Pressure	+.36 ± .028
Years of Service with Median Systolic Blood Pressure	−.012± .03
Years of Service with Median Diastolic Blood Pressure	+.17 ± .03
Mean Systolic Blood Pressure at Exam. with the corresponding Mean Diastolic Blood Pressure	+.6 ± .01
Mean Pulse with Median Systolic Blood Pressure	+.325± .03
Mean Pulse with Median Diastolic Blood Pressure	+.295± .03
Mean Pulse at Each Exam. with Mean Systolic Blood Pressure at that Exam.	+.28 ± .014
Mean Pulse at Each Exam. with Mean Diastolic Blood Pressure at that Exam.	+.18 ± .015
Range of Systolic Pressure, Each Exam., with Range of Diastolic Pressure, Each Exam.	+.27 ± .016
Total Range of Diastolic Pressure of Each Man with his Total Range of Systolic Pressure	+.28 ± .03
Range of Mean Systolic Pressure with Median Systolic Pressure	+.18 ± .03
Range of Mean Diastolic Pressure with Median Diastolic Pressure	+.03 ± .032
Range of Mean Systolic Blood Pressure of Each Exam. with the Number of Exams. given that Man	+.23 ± .03
Range of Mean Diastolic Blood Pressure of Each Exam. with Number of Exams. given that Man	+.24 ± .03
Range of Systolic Blood Pressure at Each Exam. with Number of Readings at that Exam.	+.34 ± .015
Range of Diastolic Blood Pressure at Each Exam. with Number of Readings at that Exam.	+.45 ± .014
Total Range of Systolic Blood Pressure of Each Man with Number of Readings given that Man	+.31 ± .03
Total Range of Diastolic Blood Pressure of Each Man with Number of Readings given that Man	+.29 ± .03
Pulse Pressure with Median Systolic Blood Pressure	+.75 ± .018
Pulse Pressure with Median Diastolic Blood Pressure	−.05 ± .03
Range of Mean Systolic Blood Pressure of Each Man with the Range of his Mean Pulse Pressures	+.59 ± .02
Range of Mean Diastolic Blood Pressure of Each Man with the Range of his Mean Pulse Pressures	+.29 ± .03
Median Pulse Pressure with Mean Pulse	+.11 ± .013
Mean Pulse Pressure with Mean Pulse at Each Exam.	+.16 ± .015

SUMMARY AND CONCLUSIONS

1. During a period of four months the entire enlisted personnel of a regimental post, 976 men, were repeatedly examined with special reference to their blood pressures. Most of them were examined four times each, and the majority had four or more blood pressure readings at each examination. This mass of data was investigated by the statistical method; the summarized numerical results are shown in Tables 23 and 24.

2. Other tables show the data in greater detail, and Figures 1 to 5 present the facts graphically. These tables and graphs have been discussed briefly under appropriate subheads, and only the facts that seem most important are now repeated in summarizing.

3. (a) The diastolic pressure is more positively correlated with age, weight and length of service than is the systolic.

(b) Only a fourth of the overweight men more than forty years of age have systolic hyperpiesis, but almost half have a diastolic pressure of over 90 mm.

(c) The mean age and weight of those having a diastolic pressure of over 90 mm. are greater than the age and weight of those having a systolic pressure of over 140 mm. Both age and weight are, however, greater than the corresponding means of the entire group. The former relationship is also true for hypotensives (systolic pressure under 110 mm. and diastolic under 65 mm.) but in this case the mean age and weight are lower than the corresponding means of the entire group.

(d) Neither age nor weight is closely related to blood pressure, but the diastolic rate is less independent than the systolic, and should receive more attention.

4. Fluctuations in pulse pressure are much more dependent on variations in the systolic than in the diastolic pressure.

5. A low pulse pressure is not compensated for by a high pulse rate. In fact, the correlation is slightly positive.

6. Nervousness was largely responsible for the fact that the highest systolic pressures were often found at the first examinations, and that the systolic pressure had a tendency to drop during an examination independently of any change in the pulse rate.

7. What seems to be the most striking finding in this study is the great range in the blood pressure readings of almost every man examined. The range in diastolic pressure was higher, in proportion to that of the systolic pressure, than the relative height of the median

diastolic pressure to the median systolic pressure would lead one to expect. This is true of the variation in the readings at a single examination as well as when all the readings taken during all the examinations are considered.

8. In order, then, to standardize the method of blood pressure determinations, and to ascertain the true blood pressure of an examinee, the following technic is suggested.

(a) The examinee should be at rest for five to ten minutes before the examination.

(b) The determination should be made with the examinee sitting.

(c) At least three or four readings of each index should be made, with a short interval between readings to allow any turgescence to recede. Particular attention should be given to an accurate diastolic reading. Several readings are necessary not only to overcome an initial nervousness but also to insure a correct evaluation of the various sound phases.

(d) The examinee should return for two or three re-examinations at intervals of a few days at least, in order to be sure that high readings at the first examination were not neurogenic in origin.

(e) The median or the mean of the respective arrays of systolic and diastolic readings should be used to express the man's blood pressure level.

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HEREDITY OF THE SUBGROUPS OF GROUP A AND GROUP AB

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In 1910, von Dungern and Hirschfeld (1) reported the first observations on the occurrence of subgroups in group A and group AB. Similar observations were reported by Schütze (2), Coca and Klein (3), and Guthrie and Huck (4) more than ten years later. More recently, as a result primarily of the studies of Landsteiner and his co-workers (5, 6), it has been made probable that the existence of the subgroups is dependent upon the occurrence of two agglutinogens A_1 and A_2 in the two corresponding subgroups. Landsteiner and Levine have therefore suggested that the subgroups of group A be designated as A_1 and A_2, respectively, and that the subgroups of group AB be designated as A_1B and A_2B respectively.

The first studies on the heredity of the subgroups were made by Landsteiner and Levine in 1927 (7). In a later study (8), these authors examined 69 families with 212 children and obtained definite evidence of the hereditary nature of the subgroups. As a result of a study of the subgroups in eleven families, Thomsen, Friedenreich, and Worsaae (9) proposed a theory of heredity of the subgroups. These authors postulated that instead of three allelomorphic genes, A, B and R (Bernstein's theory), four allelomorphic genes, A_1, A_2, B and R exist, where the genes A_1, A_2, and B are dominant over gene R, and A_1 is dominant over A_2. The genotypes corresponding to the six possible phenotypes therefore are: group O: genotype RR; subgroup A_1: genotypes A_1A_1, A_1R, and A_1A_2; subgroup A_2: genotypes A_2A_2 and A_2R; group B: genotypes BB and BR; subgroup A_1B: genotype A_1B; and subgroup A_2B: genotype A_2B.

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It is at once apparent that although the theory permits the appearance of A_2 children even though neither parent belong to that subgroup, A_1 children should not appear unless one or both parents belong to subgroup A_1. In the studies of Landsteiner and Levine, three exceptions to Thomsen's theory were found. These occurred in matings of $A_2 \times O$ and $A_2 \times B$, where three A_1 children were found. For these cases, however, the authors believed that the possibility of illegitimacy might perhaps be considered. Thomsen, Friedenreich and Worsaae also quote a case of an $A_2 \times O$ family in which there were two A_1 children. Inasmuch as the A_2 parent was 80 years old, the authors suggested that there may have been a change of the phenotype because of age. In a more recent study on the heredity of the subgroups in 103 families with 283 children, Friedenreich and Zacho (10) failed to find a single exception to Thomsen's theory.

In 1930, one of us (A. W.) studied the heredity of the agglutinogens A, B, M and N in 131 families with 642 children (11). At the same time the subgroups of all group A and group AB bloods were determined. In this manner data were compiled on the heredity of the subgroups in 89 families with 440 children (see Table 1). The tests were performed by the method of von Dungern and Hirschfeld; i. e., by using group B sera which had been absorbed with approximately one-

TABLE 1

Heredity of the Subgroups A_1 and A_2

PARENTS	NUMBER OF FAMILIES	NUMBER OF CHILDREN OF GROUPS						TOTALS
		O	A_1	A_2	B	A_1B	A_2B	
$A_1 \times O$	29	57	85	5	0	0	0	147
$A_1 \times B$	8	5	11	1	9	9	2	37
$A_1B \times O$	2	0	3	0	8	0	0	11
$A_1B \times B$	2	0	6	0	3	1	0	10
$A_1 \times A_1$	9	4	27	0	0	0	0	31
$A_1 \times A_1B$	5	0	13	0	5	8	0	26
$A_2 \times O$	15	41	(2)	33	0	0	0	76
$A_2 \times B$	6	8	0	11	8	0	3	30
$A_2B \times O$	2	0	0	6	7	0	0	13
$A_2B \times B$	2	1	0	3	6	0	1	11
$A_2 \times A_2$	3	7	(1)	10	0	0	0	18
$A_1 \times A_2$	5	3	16	6	0	0	0	25
$A_1B \times A_2$	1	0	2	0	2	0	1	5
Totals	89	126	166	75	48	18	7	440

third volume of A_2 blood. One drop each of cell suspension, saline and serum were mixed in a small tube, and the mixtures were then centrifuged for three minutes at approximately 2000 revolutions per minute. The tubes were then placed in a test-tube rack which was shaken until the A_2 control had broken up into an even suspension (A_1 and A_2 controls were included in every experiment). The reactions were usually clear-cut, each ++ to +++ like the A_1 control, or completely negative. A small percentage of bloods was found giving weaker reactions, however. When the reactions were very faint, the blood was assigned to subgroup A_2, but if the reactions were distinct, the blood was assumed to belong to subgroup A_1. Whenever this was done, the diagnosis was corroborated by the existence of other bloods in the same family acting like the average A_2 or A_1 blood, respectively.

Three exceptions to the Thomsen theory were found in two families. We recently attempted to confirm the reactions in these families with the aid of an immune serum against A_2 in addition to absorbed group B sera. In one of the families, $A_2 \times A_2$ with one A_1 child, the mother refused re-examination of the blood. She was visited during her husband's absence and answered a rather direct question in a suspicious manner. In the other family, $A_2 \times O$ with one O child, one A_2 child, and two A_1 children, the bloods were obtained without difficulty. The re-examination of these bloods fully confirmed the results previously obtained (see Table 2). The mother was questioned concerning the

TABLE 2

BLOOD OF	TESTED WITH SERA						GROUP
	Group A	Group B	Absorbed B sera		Anti-O Immune		
			1	2	1	2	
Father	—	++±	—	—	+±	+	A_2
Mother	—	—	—	—	+±	+	O
First child	—	+++	—	—	+	+	A_2
Second child	—	—	—	—	+±	+	O
Third child	—	+++	++±	+±	—	—	A_1
Fourth child	—	+++	++	+±	—	—	A_1
Standard A_1	—	+++	++	+±	—	—	
Standard A_2	—	++±	—	—	+±	+±	
Standard B	+++	—	—	—	—	—	

circumstances surrounding her marriage and the birth of the children, but nothing suspicious could be elicited. The two exceptional children were the youngest, 6 years and 7 years old, respectively.

The confirmation of Thomsen's theory depends upon evidence to show that the exceptions found were due to difficulties with the technic or illegitimacy. Thomsen has pointed out that it is difficult to determine the subgroup in new-born infants because of incomplete development of the agglutinogens. In our families, however, this explanation cannot be used, as both parents and children were in the age group giving typical subgroup reactions.

In order to determine whether or not the exceptions found to Thomsen's theory may reasonably be attributed to illegitimacy, it is necessary to know what the chances of proving non-paternity by means of the subgroups are. This is calculated as follows:

CHANCES OF PROVING NON-PATERNITY BY MEANS OF THE SUBGROUPS

According to Thomsen's theory, there are four allelomorphic genes, A_1, A_2, B and R, where A_1, A_2, and B are dominant over R and A_1 is dominant over A_2. If p_1, p_2, q, and r represent the frequencies of the four genes A_1, A_2, B and R, respectively, then

Phenotype	*Genotype*	*Frequencies*	
O	RR	r^2	(1)
A_1	A_1A_1, A_1R, A_1A_2	p_1^2, $2p_1r$, $2p_1p_2$	$p_1(p_1+2p_2+2r)$ (2)
A_2	A_2A_2, A_2R	p_2^2, $2p_2r$	$p_2(p_2+2r)$ (3)
B	BB, BR	q^2, $2qr$	$q(q+2r)$ (4)
A_1B	A_1B	$2p_1q$	(5)
A_2B	A_2B	$2p_2q$	(6)

Then, since $p_1+p_2+q+r=1$ (7)

$$r=\sqrt{O} \quad (8)$$

$$p_1=\sqrt{O+A_1+A_2}-\sqrt{O+A_2} \quad (9)$$

$$p_2=\sqrt{O+A_2}-\sqrt{O} \quad (10)$$

$$q=\sqrt{O+B}-\sqrt{O} \quad (11)$$

Formulae (8)-(11) have also been similarly derived by Wellisch and Thomsen (12).

TABLE 3

Distribution of the Subgroups

	INDIVIDUALS OF GROUP						TOTAL NUMBER OF INDIVIDUALS
	O	A_1	A_2	B	A_1B	A_2B	
Parents	113	65	33	37	10	4	262
Children	290	166	75	86	18	7	642
Totals	403	231	108	123	28	11	904
Per cent	44.58	25.56	11.95	13.61	3.09	1.21	100.00

The frequencies of the six groups, O, A_1, A_2, B, A_1B, and A_2B in our population are given in Table 3. The frequencies of the four genes in our population therefore are:

$$p_1 = 0.1548 \qquad (12)$$

$$p_2 = 0.0835 \qquad (13)$$

$$q = 0.0951 \qquad (14)$$

$$r = 0.6677 \qquad (15)$$

(It would be more strictly accurate to base these calculations only on the distribution of the groups among the parents, who would constitute a random population).

The method used for calculating the chances of proving non-paternity is similar to that given in a previous paper on the chances of proving non-paternity by blood groups (13). It is first necessary to know the frequencies of the various mother-child combinations. These are given in terms of the frequencies of the four genes in Table 4. The following possible exclusions of paternity, according to Thomsen's theory, must be taken into account.

(1) The agglutinogen A_1 cannot appear in a child's blood unless present in the blood of one or both parents. (This follows from the dominance of A_1 over A_2. On the other hand, A_2 children from A_1 parents are possible, since the genotype of the A_1 parent could be A_1A_2).

(2) The combinations A_1B parent with A_2 child and vice-versa cannot occur. (This is analogous to the impossible combination of AB parent with O child, and vice-versa, according to the Bernstein theory of the heredity of the Landsteiner blood groups).

(3) In the matings $A_1B \times B$ and $A_1B \times A_1B$, A_2B children cannot result.

TABLE 4

Frequencies of Mother-Child Combinations

MOTHERS OF GROUPS	CHILDREN OF GROUPS					
	O	A_1	A_2	B	A_1B	A_2B
O	r^2	p_1r^2	p_2r^2	qr^2	O	O
A_1	p_1r^2	$p_1[(p_1+p_2+r)^2+p_1(p_2+r)]$	$p_1p_2(p_2+2r)$	p_1qr	$p_1q(p_1+p_2+r)$	p_1p_2q
A_2	p_2r^2	$p_1p_2(p_2+2r)$	$p_2[(p_2+r)^2+p_2r]$	p_2qr	O	$p_2q(p_2+r)$
B	qr^2	p_1qr	p_2qr	$q[(q+r)^2+qr]$	$p_1q(q+r)$	$p_2q(q+r)$
A_1B	O	$p_1q(p_1+p_2+r)$	O	$p_1q(q+r)$	$p_1q(p_1+q)$	p_1p_2q
A_2B	O	p_1p_2q	$p_2q(p_2+r)$	$p_2q(q+r)$	p_1p_2q	$p_2q(p_2+q)$

TABLE 5

Heredity of the Subgroups

PARENTS	CHILDREN POSSIBLE	CHILDREN NOT POSSIBLE
1. $A_2 \times O$	O, A_2	A_1
2. $A_2 \times A_2$	O, A_2	A_1
3. $A_2 \times B$	O, A_2, B, A_2B	A_1, A_1B
4. $A_2B \times O$	A_2, B	A_1
5. $A_2B \times A_2$	A_2, B, A_2B	A_1, A_1B
6. $A_2B \times B$	A_2, B, A_2B	A_1, A_1B
7. $A_2B \times A_2B$	A_2, B, A_2B	A_1, A_1B
8. $A_1B \times O$	A_1, B	A_2
9. $A_1B \times A_1$	A_1, B, A_2B, A_1B	A_2
10. $A_1B \times A_2$	A_1, B, A_2B	A_1B, A_2
11. $A_1B \times A_2B$	A_1, B, A_2B, A_1B	A_2
12. $A_1B \times B$	A_1, B, A_1B	A_2, A_2B
13. $A_1B \times A_1B$	A_1, B, A_1B	A_2, A_2B
14. $A_1 \times O$	O, A_1, A_2	
15. $A_1 \times A_1$	O, A_1, A_2	
16. $A_1 \times A_2$	O, A_1, A_2	
17. $A_1 \times B$	O, A_1, A_2, B, A_1B, A_2B	
18. $A_1 \times A_2B$	A_1, A_2, B, A_1B, A_2B	

These three rules of heredity are illustrated in Table 5.

The chances of proving non-paternity, when the group of the unjustly accused man is known are therefore as follows:

Group of Falsely Accused Man	*Chances of Proving Non-Paternity*	
O	$p_1p_2(p_2 + 2r) + p_1p_2q$	(16)
A_1	O	(17)
A_2	$p_1p_2(p_2 + 2q + 2r) + p_1q(p_1 + q) + p_1(q + r)^2$	(18)
B	$p_1p_2(p_2 + 2r) + 3p_1p_2q$	(19)
A_1B	$p_2(p_2 + 2r) + p_1p_2q + 2p_2q(q + r)$	(20)
A_2B	$p_1p_2(p_2 + 2q + 2r) + p_1(q + r)^2$	(21)

Substituting the frequencies for our present population, we obtain the following results:

Group	*Frequency of Group (F)*	*Chances of Proving Non-Paternity (C)*	$F \times C$
O	0.4458	0.0194	0.00865
A_1	0.2555	0.0	0.0
A_2	0.1195	0.1142	0.01364
B	0.1361	0.0213	0.00290
A_1B	0.0309	0.1295	0.00400
A_2B	0.0121	0.1104	0.00134
Unknown	1.0000	0.0305	0.03053

The average chances of proving non-paternity by means of the subgroups in our population are therefore 3.05 per cent. On the other hand, the chances of proving non-paternity by means of the four agglutinogens A, B, M and N are approximately 33 per cent (13). In our series of 131 families with 642 children, we found only three exceptions to the theories of heredity of the agglutinogens A, B, M and N (11). The three exceptions found to Thomsen's theory, therefore, are ten times as many as would be expected because of illegitimacy if the theory were correct.

It is possible to further test Thomsen's theory by certain additional exclusions possible in families with more than one child. Since three genotypes are possible for subgroup A_1 (A_1A_1, A_1R, and A_1A_2), the following are the expectancies for the groups of the children in matings of A_1 with O, B, A_1, A_1B, and A_2B:

Parents	*Children Possible*
$O \times A_1$	O, A_1, and A_2
$A_1 \times A_1$	O, A_1, and A_2
$A_1 \times B$	O, A_1, A_2, B, A_1B and A_2B
$A_1 \times A_1B$	A_1, B, A_1B and A_2B
$A_1 \times A_2B$	A_1, A_2, B, A_1B, and A_2B

In these matings, however, it is apparent that if there is one child belonging to group O or group B, children of subgroup A_2 and A_2B cannot occur in the same family, and vice-versa. As may be seen from

TABLE 6

GROUPS OF PARENTS	NUMBER OF FAMILIES	NUMBER OF CHILDREN OF GROUPS					
		O	A_1	A_2	B	A_1B	A_2B
O × A_1	26	55	80	0	0	0	0
O × A_1	Family No. 10	0	0	2	0	0	0
	Family No. 33	0	1	2	0	0	0
	Family No. 109	2	4	1	0	0	0
A_1 × A_1	9	4	27	0	0	0	0
A_1 × B	7	5	10	0	9	7	0
A_1 × B	Family No. 76	0	1	1	0	2	2
A_1 × A_1B	5	0	13	0	5	8	0

Table 6, therefore, our family No. 109 is another exception to Thomsen's theory, since it contains both A_2 and O children.

It can therefore be concluded that although the present evidence indicates that the theory of Thomsen, Friedenreich and Worsaae is essentially correct, the number of exceptions found is suspiciously high. However, the possibility of illegitimacy in these cases cannot be entirely excluded. The final solution of this problem must await further studies on the heredity of the subgroups. A special study should be made to determine whether or not A_2 children can result from A_1B mothers, and vice-versa. Such a study would of course require a very large series of cases. Even if the theory is proven to be accurate, it can only add 3 per cent to the chances of proving non-paternity. At present exceptions to Thomsen's theory can at best only be considered circumstantial evidence of non-paternity.

SUMMARY AND CONCLUSIONS

Data on the heredity of the subgroups of group A in 89 families with 440 children are presented. The theory of Thomsen, Friedenreich and Worsaae of four allelomorphic genes A_1, A_2, B, and R seems to be essentially correct. Unexplained exceptions to the theory occur, however. If the subgroups are applied medicolegally, the prospects of proving non-paternity are only 3 per cent. Where such exclusions occur they can only be used as confirmatory or circumstantial evidence of non-paternity.

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THE CEPHALIC INDEX IN HOLLAND AND ITS HEREDITY

BY FRANZ BOAS

Thanks to the generous kindness of Dr. G. P. Frets, I have been able to examine his original data of measurements of Dutch Families.

I

It seemed worth while to re-examine the series taking into account the changes in head measurements which occur in growth. The calculations contained in the following were made by Miss Carolyn Adler. As

TABLE 1

Cephalic Index by Age and Sex

	AGE	CASES	MALES	FEMALES	CASES
Under	1	26	80.2	81.8	22
	1- 2	27	81.7	83.2	18
	2- 3	25	81.1	82.0	28
	3- 4	32	80.2	81.0	23
	4- 5	25	81.2	80.7	38
	5- 6	30	81.2	82.4	28
	6- 7	24	82.0	81.4	19
	7- 8	26	80.4	82.3	22
	8- 9	32	80.6	81.9	22
	9-10	31	81.3	80.8	32
	10-11	30	81.6	81.0	24
	11-12	32	81.5	80.8	37
	12-13	26	80.9	80.9	34
	13-14	26	80.7	80.8	21
	14-15	28	81.1	80.7	23
	15-16	17	80.1	80.2	28
	16-17	23	80.2	81.8	29
	17-18	25	81.8	81.9	34
	18-19	27	80.3	81.9	25
	19	683	79.7	80.9	1067

is well known the head index decreases somewhat with age [1] and there are differences between the sexes. The values obtained from Dr. Frets' material for males and females are given in Table 1.

The reduction of the cephalic index of males from 1 to 19 years may be expressed by the equation

$$i_m = 79.7 + .09\,(18 - t)$$

where t indicates the age, i the index. For females the corresponding equation for the ages from 1 to 16 is

$$i_f = 80.9 + .06\,(17 - t)$$

In order to make the material comparable all the measurements of children have to be reduced to adult males.

Although it is not justifiable to assume that this correction represents the actual index that would belong to each individual as an adult, it is a

TABLE 2

Corrections to Cephalic Indices

AGE	MALES	FEMALES
Under 1	—1.6	—2.2
1- 2	—1.5	—2.1
2- 3	—1.4	—2.0
3- 4	—1.4	—2.0
4- 5	—1.3	—1.9
5- 6	—1.2	—1.9
6- 7	—1.1	—1.8
7- 8	—1.0	—1.7
8- 9	— .9	—1.7
9-10	— .8	—1.6
10-11	— .7	—1.6
11-12	— .6	—1.5
12-13	— .5	—1.4
13-14	— .5	—1.4
14-15	— .4	—1.3
15-16	— .3	—1.3
16-17	— .2	—1.2
17-18	— .1	—1.2
18	0	—1.2

[1] See for instance my tables in Changes in Bodily Form of Descendants of Immigrants, *Washington*, 1911, pp. 144, 150, 151.

better approximation than the unchanged value of the child at its actual age. The corrections made according to the formulas given above are given in Table 2.

From the data reduced in this way I have calculated variabilities and correlations.

The average variabilities for cephalic index are as follows:

Adult Males	$\sigma^2 = 9.85$	(683 cases)
Adult Females	8.26	(1116 cases)*
Male Children (4-18 yrs.).....	11.32	(402 cases)
Female Children (4-16 yrs.).....	9.31	(357 cases)

* Including all over 17 years old.

It may well be that the larger variabilities resulting from the reduced values of children are due to the errors introduced by the assumption that all children grow in the same way. From studies of stature and weight as well as from physiological observations we know that the variability of rate of growth is considerable. Therefore, among children of the same age, those of accelerated growth will have a lesser total growth than those of retarded growth. This would result in too great a variability in the adult, when calculated from uniformly increased values. The table previously referred to [2] shows that in males there is an accelerated change in the value of the cephalic index of males between the ages of 13 and 16 years. I repeat here in Table 3 the smoothed changes as given in that table (*l.c.*, p. 144).

TABLE 3

Changes in Male Cephalic Indices with Age

AGE	CHANGE %	AGE	CHANGE %
4- 5	—.0	12-13	—.1
5- 6	—.0	13-14	—.2
6- 7	—.0	14-15	—.4
7- 8	—.0	15-16	—.2
8- 9	—.1	16-17	—.3
9-10	—.1	17-18	—.0
10-11	—.1	18-19	—.0
11-12	—.1		

[2] See note 1.

It appears that children, let us say, of 13 years who are physiologically accelerated, will have little change of head index, while those retarded will have considerably more. Just how great the influence of this error may be, cannot be determined.

II

I have pointed out repeatedly[3] that the variability of a population depends upon two factors: the variability of family lines (genotypes), and that of fraternities and that in each case both should be determined.

The data given by Dr. Frets enable us to determine the fraternal variabilities of fraternities of two, three, four, etc. children. In order to obtain a picture of the distribution of genetic lines it is necessary to reduce these values to the variability of fraternities consisting of an infinite number of children. We assume as a starting point that the variabilities of all such fraternities in a population are equal. Then the mean square variability of the averages of family lines consisting of m siblings is

$$\sigma^2_{fam,m} = \left[\left(\frac{x_1 + x_2 + \ldots + x_m}{m}\right)^2\right]$$

$$= \frac{m[x^2] + m(m-1)[xx]}{m^2}$$

$$= \left(r + \frac{1-r}{m}\right)\sigma^2$$

where x designates deviations from the general population average, σ the mean square variation of the population, r the coefficient of fraternal correlation, and brackets averages.

Since the sum of the squares of the fraternal variability,—assumed as equal for all families,—and of the family line variability must be σ^2

$$(1)^4 \quad \sigma^2_{frat,m} = (1-r)\,\frac{m-1}{m}\,\sigma^2$$

[3] On the variety of lines of descent represented in a population, *American Anthropologist*, Vol. 18 (1916), pp. 1-9.

Die Variabilität von Volksgruppen, *Anthropologischer Anzeiger*, Vol. 7 (1931), pp. 204-208. The formulas given in the latter place on p. 206 require a correction, since the assumption that the correlations of members of a fraternity from their average are zero is not correct.

In order to obtain the fraternal variability for families consisting of an infinite number of siblings these values must be multiplied by $\frac{m}{m-1}$.

It is also necessary to determine the error of the mean square deviation of families of m siblings, the deviation being taken from the family average. I designate by x the deviations from the family mean.

$$\varepsilon^2 = \left[\left\{\left(\frac{x_1^2+x_2^2+\ldots+x_m^2}{m}\right)^2 - \frac{m-1}{m}(1-r)\sigma^2\right\}^2\right]$$

$$= \left[\left(\frac{x_1^2+x_2^2+\ldots+x_m^2}{m}\right)^2\right] - \frac{(m-1)^2}{m^2}(1-r)^2\sigma^4$$

$$= \frac{m[x^4]+m(m-1)[x^2x^2]}{m^2} - \frac{(m-1)^2}{m^2}(1-r)^2\sigma^4$$

There are m numbers in a fraternity and

$$x_1 + x_2 + \ldots + x_m = 0$$

Hence

$$[x_1^2] = -[x_1x_2+x_1x_3+\ldots+x_{m-1}x_m], \text{ or}$$

$$\sigma^2_{frat,\,m} = -(m-1)\,r_1\,\sigma^2_{frat,\,m}$$

$$r_1 = -\frac{1}{m-1}$$

$$[x^2x^2] = [x^2\{r_1^2x^2+(1-r_1^2)\sigma^2_{frat,\,m}\}]$$

$$= (1+2r_1^2)\sigma^4_{frat,\,m}$$

$$= (1+2r_1^2)\frac{(m-1)^2}{m^2}(1-r)^2\sigma^4$$

Therefore

$$\varepsilon^2 = \left\{\frac{3m+m(m-1)\left(1+\frac{2}{(m-1)^2}\right)}{m^2} - 1\right\}\frac{(m-1)^2}{m^2}(1-r)^2\sigma^4$$

$$= \left\{\frac{(m+2)(m-1)+2}{m(m-1)} - 1\right\}\frac{(m-1)^2}{m^2}(1-r)^2\sigma^4$$

$$(2)\quad \varepsilon^2 = \frac{2(m-1)}{m^2}(1-r)^2\sigma^4$$

---

[4] I have given these proofs in *American Anthropologist*, N.S. 18 (1916): 3 and *Anthropologischer Anzeiger*, 7 (1931): 205.

We have seen that, in order to reduce the fraternal variabilities obtained from families consisting of m siblings to those of an infinite number of siblings, they have to be multiplied by $\frac{m}{m-1}$. The error will be increased by the same amount, the square error by $\frac{m^2}{(m-1)^2}$. We have thus as square error for the reduced value

$$\epsilon'^2 = \frac{2}{m-1}(1-r)^2\sigma^4$$

The weight to be given to each observed value reduced to families of an infinite number of siblings is $(m-1)$ times the number of families n.

The variabilities of families of m siblings (2 to 14) and their reductions are given in Table 4.

TABLE 4

Fraternal Variabilities

m	$\sigma^2_{frat,\,m}$	$\sigma^2_{frat,\,\infty}$	n	$n(m-1)$	$n(m-1)\,\sigma^2_{frat,\,\infty}$
2	3.20	6.40	152	152	972.8
3	3.69	5.53	101	202	1117.1
4	4.83	6.44	83	249	1603.6
5	4.16	5.20	39	156	811.2
6	4.42	5.30	43	215	1139.5
7	3.73	4.35	27	162	704.7
8	4.04	4.62	21	147	679.1
9	5.46	6.14	13	104	638.6
10	4.20	4.67	8	72	336.2
11	4.03	4.43	5	50	221.5
12	1.99	2.17	1	11	23.9
13	3.25	3.52	1	12	42.2
14	7.83	8.43	1	13	109.6
Total				1545	8400.0

$$\sigma^2_{frat,\,\infty} = 5.44$$

The average total square variability obtained from adults and children is 9.31. The square of the family line variability is

$$\sigma^2 - \sigma^2_{frat,\,\infty} = 3.87$$

The standard fraternal variability is $\pm$ 2.33

The standard variability of genetic lines $\pm$ 1.95

Since

$$\sigma^2_{frat.\,\infty} = (1-r)\sigma^2$$

$$r = 0.411$$

The question must be answered in how far it is justifiable to assume that the fraternal variabilities are the same throughout. If there are considerable differences the variability of the variabilities should be greater than its theoretical value. The values calculated according to equation (2) and the observed values are given in Table 5.

TABLE 5

Observed and Theoretical Variabilities

NO. OF CHILDREN	NO. OF FAMILIES	OBSERVED	THEORETICAL
2	152	21.1[1]	15.6
3	101	16.4	13.9
4	83	27.6[2]	11.7
5	39	9.6	10.0
6	43	8.7	8.7
7	27	4.0	7.6
8	21	4.7	6.8

[1] Omitting one extreme value of $\sigma^2 = 29.5$, $\epsilon^2 = 19.1$; omitting a second extreme value $\sigma^2 = 23.0$, $\epsilon^2 = 14.4$. The next highest observed value of σ^2 is 16.0.

[2] Omitting one isolated extreme value of $\sigma^2 = 39.5$, $\epsilon^2 = 16.9$. The next highest value of σ^2 is 20.5.

The great deviations in the first and third line are due to single strongly aberrant fraternities. This comparison does not justify an assumption of a considerable variability of fraternal variabilities.

III

In the discussion of measurements of the cephalic index of immigrants I have given some data showing the relation between fraternal variability and the difference between the values of the cephalic index for father and mother.[5] The summary of these data showed that when

[5] See Changes in Bodily Form of Descendants of Immigrants. *Washington* 1911, pp. 76-78; 153-154.

TABLE 6

Cephalic Index. Fraternal Variability Corrected for Infinite Number of Children Arranged According to Difference in Index of Parents

DIFFERENCE BETWEEN PARENTS	NUMBER OF CHILDREN IN FAMILY													AVERAGE WEIGHTED BY $n(m-1)$	TOTAL WEIGHT
	2	3	4	5	6	7	8	9	10	11	12	13	14		
0- 0.9	8.16 *11*	...	5.40 *9*	2.84 *3*	1.76 *1*	3.87 *2*	5.09 *3*	5.34 *1*	3.93 *1*	3.92 *1*	...	...	...	4.77	115
1- 1.9	9.36 *14*	2.63 *3*	8.99 *8*	6.58 *4*	4.84 *9*	5.10 *4*	...	6.84 *5*	4.28 *1*	3.39 *3*	...	3.52 *1*	...	5.74	220
2- 2.9	4.82 *11*	6.39 *5*	7.16 *8*	5.93 *5*	4.25 *2*	4.21 *4*	3.27 *5*	...	4.93 *2*	...	...	...	8.43 *1*	5.23	165
3- 3.9	8.72 *11*	8.42 *8*	7.31 *8*	3.00 *6*	7.18 *5*	4.21 *5*	...	...	...	...	...	...	...	6.02	130
4- 4.9	5.92 *3*	6.65 *15*	6.88 *5*	11.21 *2*	7.27 *4*	6.94 *2*	6.37 *3*	9.21 *2*	2.61 *1*	...	2.17 *1*	...	...	6.67	145
5- 5.9	7.32 *5*	3.74 *2*	5.16 *4*	4.21 *3*	3.95 *4*	4.06 *3*	6.55 *2*	1.53 *1*	...	...	...	...	...	4.51	93
6- 6.9	5.40 *9*	6.63 *2*	3.19 *3*	2.95 *1*	3.47 *2*	2.26 *2*	5.01 *1*	...	6.76 *1*	...	...	...	...	4.27	64
7- 7.9	4.64 *4*	...	3.21 *3*	8.41 *3*	3.07 *1*	...	...	2.39 *1*	...	...	...	...	...	4.81	38
8- 8.9	...	...	5.21 *1*	...	13.30 *1*	2.39 *1*	...	12.70 *1*	3.01 *1*	8.07 *1*	...	...	...	7.46	41
9- 9.9	...	...	5.30 *1*	...	...	7.15 *1*	5.55 *2*	...	...	...	...	...	...	12.15	23
10-10.9	2.88 *2*	.50 *1*	...	3.80 *1*	...	...	...	...	6.84 *1*	...	...	...	...	4.91	17
11-11.9	...	...	12.40 *1*	7.60 *1*	...	...	4.16 *1*	...	...	...	...	...	...	6.90	14
Total Number of Families	*70*	*36*	*51*	*29*	*29*	*24*	*17*	*11*	*8*	*5*	*1*	*1*	*1*	283 Families 1348 Children	1065

the difference between the values of the cephalic index of the parents was—

From 0 to 2.9, the variability of the children was ± 6.8 (1102 cases)
From 3 to 5.9, the variability of the children was ± 6.7 (736 cases)
From 6 to 8.9, the variability of the children was ± 8.3 (317 cases)
9 and more, the variability of the children was ± 13.0 (108 cases)

The increase calculated from the detailed tables and assumed to be proportional to the amount of difference d between the parents may be expressed by the formula

$$\sigma_d^2 = 6.43 + .22d$$

For the Frets material (all children reduced to male adults) the fraternal variabilities for varying differences between parents, each fraternal variability reduced to an infinite number of children by multiplication by $\frac{m}{m-1}$, are given in Table 6. The average for fraternities without regard to the number of children has been computed as before by giving each average for a family of m children the weight $m - 1$.

Assuming again a linear relation, these fraternal variabilities may be expressed by the equation

$$\sigma_d^2 = 5.06 + .17d$$

a value which agrees fairly well with the value previously obtained. The two series indicate that the fraternal variability increases first very slowly with the increasing difference between parents, and that a rapid increase begins only when the difference of the cephalic indices between the parents exceeds 6 or 8 units. This probably means that real genetic differences are not pronounced unless the differences between the parents attain high values.

IV

In order to investigate the question whether any dominance in the cephalic index exists I have assumed a simple regression relation between the indices of children and those of their parents. This would be the result of no dominance. If there should be dominance, there would result more or less regular deviations from the theoretical regression values.

TABLE 7

Correlation of Cephalic Index of Father and Mother with Difference Between Actual and Expected Value of Average of Fraternity Figures in Table are Theoretical Value Minus Actual Value

y = INDEX OF MOTHER

x = INDEX OF FATHER	71.5	72.5	73.5	74.5	75.5	76.5	77.5	78.5	79.5	80.5	81.5	82.5	83.5	84.5	85.5	86.5	87.5	88.5	TOTAL WEIGHT
65.5	....	....	....	....	−2.2 *13*	....	....	....	....	....	....	....	....	....	....	....	....	....	13
71.5	....	....	....	....	− .3 *16*	....	....	....	....	....	....	....	....	....	....	....	....	....	16
72.5	....	....	....	....	....	....	−3.1 *13*	....	....	....	....	....	+1.9 *16*	....	....	....	....	....	29
73.5	....	....	....	+6.4 *13*	....	−4.2 *13*	....	−2.5 *31*	+1.7 *28*	....	0 *15*	....	....	....	....	....	....	....	100
74.5	....	....	....	....	....	− .9 *28*	....	+1.3 *14*	....	− .1 *16*	+4.1 *28*	....	+2.2 *16*	....	....	....	....	....	102
75.5	...	...	...	...	...	+1.5 *59*	...	−3.0 *15*	+ .6 *15*	−1.2 *13*	− .9 *41*	....	+ .9 *30*	....	....	−1.2 *15*	....	....	188
76.5	....	....	....	+ .9 *14*	+4.4 *15*	....	+1.0 *30*	+ .7 *58*	+ .1 *44*	−1.1 *117*	....	−4.4 *13*	−6.4 *13*	....	....	....	−1.2 *14*	....	318
77.5	....	....	+ .9 *14*	+2.3 *28*	− .2 *45*	+1.0 *13*	− .7 *56*	+ .1 *47*	−1.4 *59*	+2.3 *58*	−1.3 *28*	+ .1 *72*	+2.7 *29*	−1.6 *44*	+1.3 *15*	....	....	....	508
78.5	+ .9 *14*	....	....	....	+ .2 *28*	− .7 *30*	+1.5 *13*	0 *98*	−3.8 *29*	−2.5 *28*	+2.2 *55*	− .3 *62*	+ .1 *16*	+ .9 *29*	....	−1.0 *16*	....	+ .5 *13*	431

TABLE 7—*Continued*

x = INDEX OF FATHER	y = INDEX OF MOTHER	TOTAL WEIGHT
65.5	75.5	13
71.5	75.5	16
72.5	77.5	29
73.5	74.5	100
74.5	76.5	102
75.5	76.5	188
76.5	76.5	318
77.5	77.5	508
78.5	78.5	431
79.5	78.5	28
80.5	79.5	117
81.5	73.5	15
81.5	74.5	28
81.5	75.5	41
81.5	76.5	117
81.5	77.5	55
81.5	78.5	55
81.5	79.5	28
81.5	80.5	28
82.5	77.5	72
82.5	78.5	62
82.5	79.5	13
82.5	80.5	13
83.5	72.5	16
83.5	74.5	16
83.5	75.5	30
83.5	76.5	13
83.5	77.5	29
83.5	78.5	16
84.5	77.5	44
84.5	78.5	29
85.5	77.5	15
86.5	75.5	15
86.5	78.5	16
87.5	76.5	14
88.5	78.5	13

TABLE 7—*Continued*

x = INDEX OF FATHER	71.5	72.5	73.5	74.5	75.5	76.5	77.5	78.5	79.5	80.5	81.5	82.5	83.5	84.5	85.5	86.5	87.5	88.5	TOTAL WEIGHT
79.5	....	....	....	....	+1.4 42	+1.7 42	− .2 101	+2.0 75	+ .7 73	+ .7 29	+ .7 15	− .4 43	+ .6 29	− .1 44	+ .5 13	....	....	....	506
80.5	....	....	....	−1.6 29	+ .3 41	−2.2 57	+ .3 29	+ .5 59	0 89	+ .7 115	− .3 54	−2.2 40	+ .4 39	....	....	....	....	....	552
81.5	....	....	....	....	+2.7 27	+2.0 43	−1.0 44	− .9 67	− .7 28	+ .3 101	+ .5 72	+ .8 58	....	+1.7 15	....	....	....	....	455
82.5	....	....	....	....	....	−1.0 27	−2.2 29	+ .3 43	+1.6 29	− .5 44	+1.2 27	−5.1 26	+ .3 56	+1.3 16	....	−3.2 14	....	....	311
83.5	....	....	+ .1 15	+2.4 16	....	+ .3 16	− .7 27	−2.5 16	−5.2 28	− .8 57	− .7 27	− .9 15	+4.2 15	+ .9 15	....	....	....	....	247
84.5	....	....	....	....	+1.5 14	....	+2.9 42	....	−1.9 29	−2.8 14	+1.3 30	−6.1 13	− .8 13	....	....	....	....	....	155
85.5	....	....	....	....	....	....	− .6 16	....	....	....	....	−1.0 15	+1.7 13	....	....	....	....	....	44
86.5	....	....	....	....	....	+1.0 30	....	....	+2.7 13	− .9 15	....	....	....	....	....	....	....	....	58
87.5	....	....	....	....	....	....	....	....	....	....	....	....	−2.5 14	....	....	....	....	....	14
88.5	....	....	....	....	....	....	....	....	−6.0 15	....	....	....	....	....	....	....	....	....	15
	14	0	29	100	241	358	400	523	479	607	392	357	299	163	28	45	14	13	4062

If x is called the deviation of the father from the average of fathers 79.6; y the deviation of the mother from the reduced average of mothers 79.8; z the deviation of children from the reduced average of children we find

$$(3) \quad z = .21\,x + .30\,y$$

The coefficients of correlation are

$$r_{xy} = -.006; \quad r_{xz} = .261; \quad r_{yz} = .343$$

In Table 7 are given differences between the observed values and those obtained assuming our regression formula. Roman figures represent these differences, Italic figures the numbers in each group. It will be observed that the distribution is apparently quite irregular. If there was any regularity it would appear as a correlation between the values of x and z and their differences v.

A calculation of the regression gives

$$v = -.07\,x - .07\,y$$

In other words no correlation. This would be possible only if there were no correlation, or if positive or negative deviations at the extreme ends were balanced by others in the opposite sense in the central region. This balance is extremely unlikely and it seems more plausible that the

TABLE 8

INDEX OF FATHER	INDEX OF MOTHER: < 78 — C. I.	< 78 — Cases	INDEX OF MOTHER: 78.0-80.9 — C. I.	78.0-80.9 — Cases	INDEX OF MOTHER: > 81 — C. I.	> 81 — Cases	
< 78	77.56	370	79.36	515	80.26	389	Actual average
	78.02		79.18		80.25		Theoretical value
	+.46		−.18		−.01		Difference
78.0-80.9	78.93	426	79.55	595	80.76	468	Actual average
	78.87		79.81		80.86		Theoretical value
	−.06		+.26		+.10		Difference
> 81	79.06	346	81.35	499	81.53	454	Actual average
	79.67		80.54		81.45		Theoretical value
	+.61		−.81		−.08		Difference

deviations are irregular, that is to say that there is no dominance of either elongated or round forms.

The improbability of any dominance appears also in a grouping of the actual and theoretical values. In Table 8 are given the averages of all actual observations, the averages of all theoretical values calculated from (3) and their differences. These were obtained from all the combinations of units of cephalic index for father and mother.

It appears from Table 8 that for the same combinations of values for father-mother and mother-father entirely different values result.

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THE HEIGHTS AND WEIGHTS OF AMERICAN COLLEGE WOMEN

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In a recent issue of this journal the author reported an analysis of the age, height and weight data of 23,122 college men(1). These data for men were collected from ten colleges or universities in various parts of the country and at the same time similar data were collected for college women. The primary purpose of assembling these data was that they might be used to test the suitability of the medico-actuarial tables(2) of "normal" weights when these are used as standards for college students. The plan of procedure was to build from these data tables of average weights for college students and then to compare these averages with those given in medico-actuarial tables. In order that these new tables should be reasonably representative of college students of this country, basic data were requested from various types of institutions in different sections of the country. For women such data were received from Cornell University, Leland Stanford University, Michigan State Normal College, University of Minnesota, North Carolina College for Women, Smith College, University of Wisconsin, and the University of Texas. Each of these eight institutions sent records of approximately 2500 women students but in the tabulations only the records of those between 16 and 21 years of age were used. The total number of women's records included in the study was 17,127.

The specifications for the collection of these data for women were that the measurements should have been made during the academic years 1928-29 or 1929-30; that the students should have been weighed and measured wearing only an examining gown of known weight; that

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standardized measuring instruments and techniques should have been used; and that measurements should have been recorded according to the method described for the college men(1).

ENTIRE GROUP OF COLLEGE WOMEN

Scattergrams of weight in pounds to the nearest pound and of height in inches to the nearest inch were prepared for each age group of each college. Halves in years, in inches or in pounds were thrown alternately to the group above and to the group below the half. The scattergrams for the individual age groups of the various colleges were then combined into single scattergrams for each age group; and finally, these for the several age groups were combined into one scattergram for the group as a whole (Figure 1). From these several scattergrams the various statistical constants which are presented in Tables 1 to 7 were computed. Table 1 presents data for the 17,127 college women between 16 and 21 years of age and shows for each inch in height the number of cases, the mean weight, its probable error, and the standard deviation

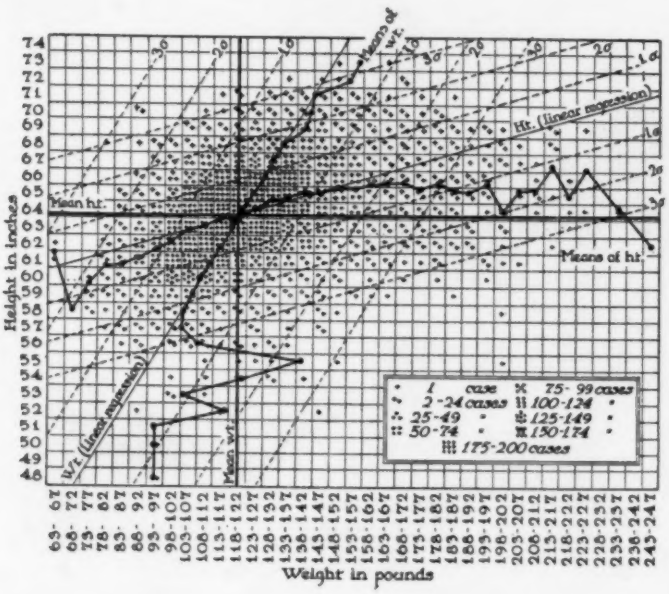

FIG. 1. SCATTERGRAM OF HEIGHTS AND WEIGHTS OF 17,127 COLLEGE WOMEN, AGES 16 TO 21 YEARS

and coefficient of variability of individual cases from the mean. Tables 2 to 7 present similar data for each age group separately; and Table 8 is a summary table which gives for each age group the mean height, the mean weight, the standard deviations from these means, and the coefficient of correlation between height and weight.

TABLE 1

Average Weights—College Women—Ages 16 to 21 Years

HEIGHT	MEAN WEIGHT	S. D.	C. V.	CASES Number	CASES Per cent
48	95	.....	....	1	.005
50	95	.....	....	1	.005
51	95	.....	....	1	.005
52	116.67±10.72	27.54±7.58	23.61	3	.017
53	103.75± 1.62	4.79±1.62	4.62	4	.023
54	121.67± 4.05	14.72±2.87	12.10	6	.04
55	139.17± 8.98	32.62±6.35	23.44	6	.04
56	108.75± 2.14	14.22±1.52	13.08	20	.11
57	103.33± 1.78	15.86±1.26	15.35	36	.21
58	103.51± 1.03	16.25± .73	15.70	114	.67
59	106.95± .57	14.57± .40	13.62	302	1.76
60	108.74± .32	13.38± .22	12.30	811	4.74
61	112.14± .27	15.01± .19	13.39	1402	8.19
62	115.25± .21	15.01± .15	13.02	2358	13.77
63	118.99± .19	14.65± .13	12.31	2826	16.50
64	120.79± .19	15.44± .14	12.78	2932	17.12
65	124.41± .21	15.66± .15	12.59	2505	14.63
66	128.03± .26	16.24± .18	12.68	1823	10.64
67	131.58± .34	16.30± .24	12.39	1036	6.05
68	133.56± .49	17.41± .35	13.04	576	3.36
69	140.97± .85	20.23± .60	14.35	257	1.50
70	142.47± 1.40	18.17± .99	12.75	77	.45
71	143.70± 2.50	17.79±1.77	12.38	23	.13
72	154.00± 4.70	15.57±3.32	10.11	5	.29
73	157.50± 5.06	10.61±3.58	6.74	2	.011
Mean Ht. 63.75±.01	120.69± .09	17.10± .06	14.17	17127	....

TABLE 2

Average Weights—College Women—Age 16 Years

HEIGHT	MEAN WEIGHT	S. D.	C. V.	CASES	
				Number	Per cent
57	96.67±3.64	7.64±2.10	7.90	3	.42
58	70	.....	....	1	.14
59	105.00±2.54	11.30±1.70	10.76	10	1.42
60	107.34±1.44	11.92±1.02	11.10	32	4.56
61	112.55±1.32	14.02± .93	12.46	51	7.26
62	116.68±1.09	16.23± .77	13.91	101	14.39
63	114.55± .85	14.67± .60	12.81	134	19.09
64	120.58± .92	14.42± .65	11.96	112	15.95
65	123.65±1.06	15.75± .75	12.74	100	14.24
66	129.24±1.47	18.46±1.04	14.28	72	10.26
67	129.44±1.89	18.77±1.33	14.50	45	6.41
68	133.80±3.65	26.54±2.53	19.84	25	3.56
69	138.50±3.90	17.33±2.61	12.51	10	1.42
70	137.50±6.53	16.77±4.00	12.20	4	.57
71	140	.....	....	2	.28
Mean Ht. 63.82±.06	120.04± .45	17.77± .32	14.80	702	....

TABLE 3

Average Weights—College Women—Age 17 Years

HEIGHT	MEAN WEIGHT	S. D.	C. V.	CASES Number	CASES Per cent
50	95	.....	....	1	.03
51	.....	.....	....	....	....
52	.....	.....	....	....	....
53	105	.....	....	1	.03
54	120	.....	....	1	.03
55	135	.....	....	2	.05
56	118.75±4.43	13.15±3.14	11.07	4	.11
57	102.22±2.82	12.53±1.99	12.26	9	.24
58	102.24±1.71	13.62±1.21	13.32	29	.79
59	106.67±1.15	13.91± .82	13.04	66	1.80
60	108.70± .68	13.20± .48	12.14	170	4.62
61	112.09± .58	15.18± .41	13.54	314	8.54
62	113.96± .43	14.27± .30	12.52	499	13.57
63	117.28± .42	15.03± .29	12.82	594	16.16
64	121.06± .42	15.98± .30	13.20	664	18.06
65	124.04± .45	15.52± .32	12.51	539	14.66
66	128.52± .54	16.17± .38	12.58	411	11.18
67	126.82± .76	15.82± .54	12.47	195	5.30
68	130.29±1.03	16.72± .73	12.83	120	3.26
69	138.84±1.99	19.35±1.41	13.94	43	1.17
70	132.78±4.53	20.17±3.21	15.19	9	.24
71	157.50±6.82	20.21±4.82	12.83	4	.11
72	.....	.....	....	....	....
73	150	.....	....	1	.03
Mean Ht. 63.69±.03	119.85± .19	16.84± .13	14.05	3676	....

TABLE 4

Average Weights—College Women—Age 18 Years

HEIGHT	MEAN WEIGHT	S. D.	C. V.	CASES Number	CASES Per cent
48	95	.....	....	1	.02
52	145	.....	....	1	.02
53	103.33±2.25	5.77±1.59	5.58	3	.05
54	.....	.....	....	....	....
55	117.50	.....	....	2	.03
56	109.17±5.60	20.35±3.96	18.64	6	.10
57	103.13±2.60	10.91±1.84	10.58	8	.14
58	103.98±1.39	13.63± .98	13.11	44	.75
59	109.11± .92	15.21± .65	13.94	124	2.10
60	109.43± .57	14.03± .40	12.82	282	4.78
61	111.62± .46	13.63± .29	12.21	492	8.34
62	115.45± .34	14.89± .24	12.90	857	14.53
63	118.59± .33	15.39± .24	12.98	972	16.47
64	120.60± .33	15.26± .23	12.65	999	16.93
65	124.20± .36	15.49± .25	12.47	846	14.34
66	128.03± .47	16.69± .33	13.04	588	9.97
67	131.68± .58	16.24± .41	12.33	357	6.05
68	135.11± .88	17.79± .63	13.17	184	3.12
69	143.13±1.56	23.01±1.10	16.08	99	1.68
70	142.88±2.65	20.05±1.88	14.03	26	.44
71	133.13±3.49	14.62±2.47	10.98	8	.14
72	.....	.....	....	....	....
73	165	.....	....	1	.01
Mean Ht. 63.69±.02	120.72± .15	17.33± .11	14.36	5901	....

TABLE 5

Average Weights—College Women—Age 19 Years

HEIGHT	MEAN WEIGHT	S. D.	C. V.	CASES	
				Number	Per cent
54	122.00±4.80	15.91±3.39	13.04	5	.13
55	200	.....	....	1	.02
56	105.83±3.07	11.14±2.17	10.53	6	.15
57	109.50±4.07	19.07±2.88	17.42	10	.26
58	104.58±1.84	13.34±1.30	12.76	24	.63
59	104.35±1.27	14.85± .90	14.23	62	1.62
60	108.40± .64	12.73± .45	11.74	181	4.72
61	111.50± .58	14.77± .41	13.25	296	7.71
62	115.73± .44	14.40± .31	12.44	492	12.82
63	118.46± .40	14.76± .28	12.46	622	16.21
64	120.12± .38	14.61± .27	12.16	670	17.46
65	124.66± .44	15.78± .31	12.66	571	14.87
66	127.80± .48	14.55± .34	11.38	416	10.84
67	133.40± .63	14.55± .44	10.91	247	6.44
68	132.62± .94	16.60± .66	12.52	143	3.73
69	141.09±1.32	16.26± .93	11.52	69	1.80
70	142.50±2.37	14.88±1.67	10.44	18	.47
71	142.50±4.01	11.90±2.84	8.35	4	.10
72	.....	.....	....	....	....
73	150	.....	....	1	.03
Mean Ht.					
63.86±.02	121.03± .18	16.71± .13	13.81	3838	....

TABLE 6

Average Weights—College Women—Age 20 Years

HEIGHT	MEAN WEIGHT	S. D.	C. V.	CASES Number	CASES Per cent
51	95	.....	....	1	.05
52	102.50	.....	....	2	.10
53	.....	.....	....	....	....
54	.....	.....	....	....	....
55	130	.....	....	1	.05
56	102.50	.....	....	2	.10
57	145	.....	....	1	.05
58	97.92±2.21	11.37±1.57	11.61	12	.62
59	105.21±1.81	13.14±1.28	12.49	24	1.23
60	106.84± .88	12.77± .62	11.95	95	4.87
61	113.89± .94	17.01± .67	14.94	148	15.19
62	115.72± .69	16.84± .49	14.55	271	13.90
63	118.39± .56	14.61± .40	12.34	311	15.96
64	121.48± .67	15.88± .42	13.07	321	19.46
65	125.12± .59	15.26± .42	12.20	299	15.34
66	128.88± .77	17.26± .55	13.39	227	11.65
67	135.16±1.08	17.96± .76	13.29	126	6.46
68	133.00±1.36	16.21± .96	12.19	65	3.34
69	143.86±3.20	22.25±2.26	15.47	22	1.13
70	146.33±3.43	19.68±2.42	13.45	15	.77
71	151.67±7.37	18.93±5.21	12.48	3	.15
72	150.00±7.02	18.03±4.96	12.02	3	.15
Mean Ht. 63.85±.04	121.74± .27	17.99± .19	14.78	1949	....

TABLE 7

Average Weights—College Women—Age 21 Years

HEIGHT	MEAN WEIGHT	S. D.	C. V.	CASES Number	CASES Per cent
56	102.50	.....	....	2	.19
57	89.00±2.48	8.22±1.75	9.24	5	.47
58	101.67±2.97	7.63±2.10	7.50	3	.28
59	105.94±2.43	14.40±1.72	13.59	16	1.51
60	110.29±1.26	13.34± .89	12.10	51	4.82
61	113.86±1.20	17.86± .85	15.66	101	9.55
62	115.00± .89	15.52± .63	13.50	138	13.04
63	117.98± .71	14.70± .50	12.46	193	18.24
64	122.41± .82	15.72± .58	12.84	166	15.69
65	125.07± .95	17.23± .67	13.78	150	14.18
66	124.40± .99	15.38± .70	12.36	109	10.30
67	132.95±1.30	15.71± .92	11.82	66	6.24
68	131.79±1.89	17.49±1.34	13.27	39	3.69
69	128.57±1.89	10.46±1.33	8.14	14	1.32
70	149.00±4.70	15.57±3.32	10.45	5	.47
71	152.50	.....	....	2	.19
72	170	.....	....	1	.09
Mean Ht. 63.74±.05	120.73± .36	17.50± .26	14.50	1061	....

TABLE 8

Summary Table—Women Students of All Colleges

AGE	MEAN		STANDARD DEVIATION		PARTIAL STANDARD DEVIATION		r wt.ht.	NO. CASES
	Height	Weight	Height	Weight	Of Height with Weight held constant	Of Weight with Height held constant		
16	63.82±.06	120.04±.45	2.27±.04	17.77±.32	2.07±.29	16.17±.29	+.4150±.0211	702
17	63.69±.03	119.85±.19	2.29±.02	16.84±.13	2.11±.12	15.49±.12	+.3922±.0094	3676
18	63.69±.02	120.72±.15	2.34±.01	17.33±.11	2.13±.10	15.74±.10	+.4181±.0072	5901
19	63.86±.02	121.03±.18	2.27±.02	16.71±.13	2.06±.13	16.71±.13	+.4199±.0090	3838
20	63.85±.04	121.74±.27	2.35±.03	17.99±.19	2.11±.17	16.16±.17	+.4398±.0123	1949
21	63.74±.05	120.73±.36	2.33±.03	17.50±.26	2.13±.24	16.26±.24	+.4037±.0173	1061
All ages	63.75±.01	120.69±.09	2.33±.008	17.10±.06	2.11±.06	15.51±.06	+.4215±.0042	17127

Age. Since the numbers of college women below 16 and over 21 years of age were small, our tabulations were limited to the ages 16 to 21 years. The division of cases among the several age groups is as follows: 702 at 16 years; 3676 at 17 years; 5901 at 18 years; 3838 at 19 years; 1949 at 20 years; and 1061 at 21 years. The medico-actuarial tables were based upon the examination of 520 women at 16 years of age; 727 at 17 years; 1253 at 18 years; 1809 at 19 years; 2763 at 20 years; and 4126 at 21 years.

The age distribution of these college women, in comparison to the college men, shows that women tend to enter college at a slightly younger age than do the men. Of the women, 4.1 per cent are 16 years of age as compared to 2.6 per cent of the men; and 21.5 per cent of the women are 17 years of age, as compared to 14 per cent of the men.

Height. The scattergram showing the distribution of heights and weights for all of the women between 16 and 21 years of age is shown in Figure 1. The scattergrams for the individual age groups have been omitted because of their similarity to the ones which have been published for the men(1). Figure 1 also shows the theoretical linear regression lines of height for weight and of weight for height(3); and the regressions of the computed means of height for each weight group and of weight for each inch in height.

The partial standard deviations(3) of height with weight held constant, $2.07 \pm .29$ inches, and of weight with height held constant, $16.17 \pm .29$ pounds, are practically the same as the averages of the standard deviations from the various means which make up the non-linear regression lines; viz., 2.12 inches and 15.46 pounds, respectively. The areas included between one, two and three standard deviations from the theoretical means are shown in the figure. These areas are of approximately the same magnitude as those shown for the men.

Theoretical regression lines, such as those shown in Figure 1, frequently give a better picture of a regression which tends to be linear than do the more irregular lines connecting the computed means. This is particularly true for the portions of the scattergrams in which the number of cases is small. In this instance, the regressions of height on weight and of weight on height are practically linear for the great mass of the data, but tend to become somewhat non-linear below 58 inches in height and 105 pounds in weight and above 68 inches in height and 145 pounds in weight. In the scattergrams for each age group

separately, the differences between the linear regression lines and the computed means are less than the differences shown in Figure 1 in which all ages have been grouped together.

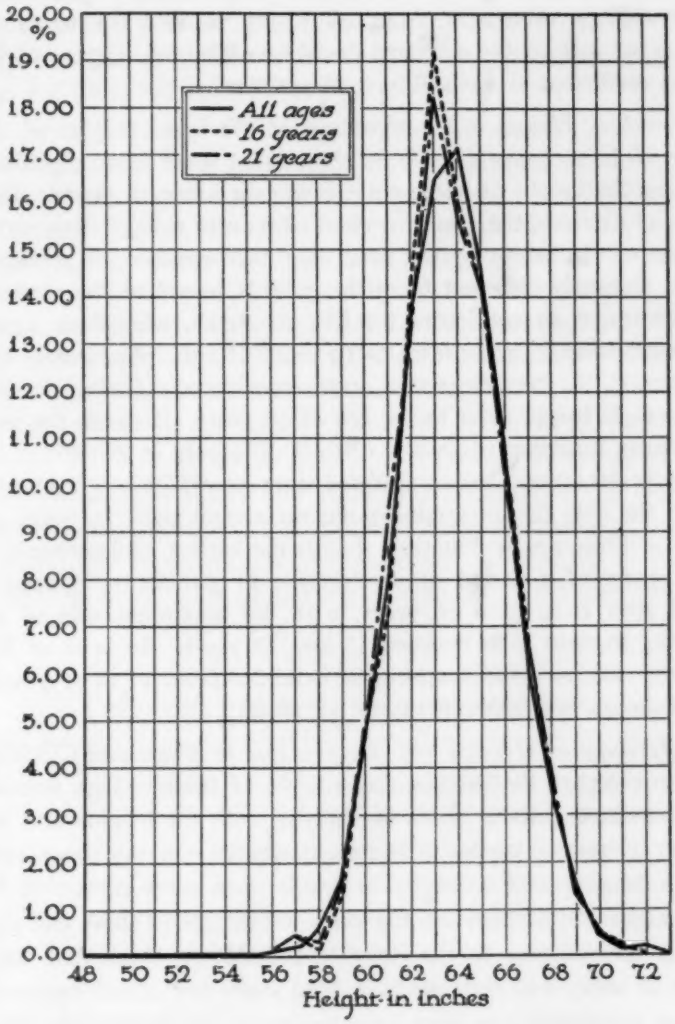

FIG. 2. DISTRIBUTION CURVES OF HEIGHT FOR COLLEGE WOMEN

Frequency distribution curves of height for the entire age group and for the 16 and 21 year old groups separately are shown in Figure 2. Each of these curves shows a practically normal distribution, except for a slight skewing of the curve toward the lower heights, and the curves are so similar that they almost coincide. The range in height of these 17,127 college women is from 48 to 73 inches; the mean height, 63.75 ± .01 inches; the standard deviation of height, 2.33 ± .01 inches; and the coefficient of variability, 3.66 per cent.

Growth in Height. A comparison of the mean heights of the age groups 16 to 21 years (Table 8) shows that there is no significant increase in the height of these college women after 16 years. In other words, as a group, the young women who enter college have completed their growth in height by the time they have reached 16 years of age. This is distinctly different from the growth record of the women who were measured as applicants for life insurance, who show significant annual increases in growth up to 19 years of age. Apparently the college women, like the college men, have experienced a distinct acceleration of growth in height prior to the age of 16 years. Between the men and the women, however, there is a distinct difference in growth in height; for, while the women have completed their growth in height by 16 years of age, the men do not attain maximum stature until 19 years of age. This sex difference is doubtless due to the earlier adolescence of girls. Boas(4) found a period of acceleration in growth of Horace Mann School girls from 9 to 16 years, with the maximum rate of growth occurring in most girls between 11 and 12 years. In boys of Newark Academy this period of acceleration extended from 11 to 17 years, with the maximum rate between 14 and 15 years.

Differences in Heights and Weights due to Shoes and Clothing. In order to compare the heights and weights of these college women who were examined without shoes or clothing with the heights and weights of other groups of women who were measured wearing shoes and ordinary clothing, it was necessary to decide upon some correction for the extra height due to shoes and the extra weight due to shoes and clothing. Various estimates as to the extra height due to shoes and the extra weight of shoes and clothing have been made but actual measurements of these do not seem to have been reported. In September, 1930, 910 girls at the University of Minnesota were weighed and measured in ordinary shoes and clothing and stripped except for an examining gown

of known weight. An analysis of these measurements showed that the wearing of shoes increased the average heights of these girls by 1.73 ± .01 inches and that the weight of their shoes and clothing increased their average weights by 2.49 ± .02 pounds. The variability of the extra height due to shoes, as measured by the standard deviation, was ± .49 inches; and the range from ¼ of an inch to 3⅜ inches. The standard deviation of the weight of shoes and clothing was ± .79 pounds; and the range from ½ to 4¾ pounds.

Comparative Heights of Young American Women. Data concerning the heights and weights of American women seem to be available only for college women and for the women who were applicants for life insurance. Hence, the only group with which we are able to compare these college women is this life insurance group, and even this comparison is not entirely satisfactory because these life insurance measurements were made approximately twenty years ago and included both shoes and clothing. However, since these seem to be the only data available, we have attempted to correct for the differences in measuring procedures by subtracting from the average heights and weights of the life insurance group the average increases in these measurements due to shoes and clothing as determined by the study described in the preceding paragraph. These corrections, however, do not take into consideration differences due to changes in women's dress over the twenty year period which has elapsed between the taking

TABLE 9

Comparative Heights of Young American Women

AGE	COLLEGE WOMEN	MEDICO-ACTUARIAL DATA *
16	63.82±.06	61.96±.08
17	63.69±.03	62.31±.06
18	63.69±.02	62.59±.04
19	63.86±.02	62.72±.04
20	63.85±.04	62.67±.03
21	63.74±.05	62.62±.02
All ages	63.75±.01	62.59±.01

* Corrected for height without shoes by subtracting 1.73 inches from mean heights with shoes as computed from medico-actuarial data.

of the measurements. How much difference these changes in dress have made in height and weight we have no way of knowing; so the best we can do is to call attention to them and permit the reader to speculate upon their importance.

Table 9, which presents comparative heights of these college women and the women of the medico-actuarial group, shows that the college women are significantly taller at each age from 16 to 21 years than the women who were examined for life insurance. At 16 years the difference is $1.86 \pm .10$ inches; at 18 years, $1.10 \pm .05$ inches; at 21 years, $1.12 \pm .06$ inches; and for all ages taken together, $1.16 \pm .01$ inches. Certainly, even though our correction for the average height of heels may not be absolutely accurate, these differences seem significant. In comparing groups, however, which were measured twenty years apart, the fact that for years both college men(5) and college women have been showing a gradual increase in height needs to be taken into consideration; and this raises the question as to whether the increase in height of college women over the twenty years between the taking of the measurements is sufficient to account for the differences here noted between the groups. It is difficult to answer this question positively but, since Mosher(6) found that the average increase in the height of women students at Stanford, Smith and Vassar for the twenty year period, 1900 to 1920, was 0.5 of an inch, it is very probable that the differences shown in Table 9 represent real differences between the groups and that the college women are actually taller than the women who are examined for life insurance. If it were possible to compare these college women with other women of the general population, it is probable that still greater differences would be found because women who hold life insurance policies as a group are distinctly select socially and economically, in comparison to the general population. The chief reasons for the greater height of the college women, as well as for their acceleration in growth during the pre-college years, probably is that during childhood they have had better than average food, care and living conditions.

Variability of Height with Age. The variability of height with age, as measured by the standard deviation, varies from $2.27 \pm .04$ inches in the 16 year old group to $2.35 \pm .03$ inches in the 20 year old group. The partial standard deviations of height with weight held constant by means of a statistical formula(3) vary from $2.07 \pm .29$ to $2.13 \pm .10$ inches. None of these differences, however, are statistically significant.

Weight. The frequency distributions for weight of the entire group and of the 16 and 21 year old groups separately are shown in Figure 3. These curves approach normal distribution, except for a skewing toward the higher weights, and practically coincide. The range in weight of the group as a whole is from 64 to 245 pounds; the mean weight, 120.69 ± .09 pounds; the standard deviation of weight, 17.10 ± .06 pounds; and the coefficient of variability, 14.17 per cent.

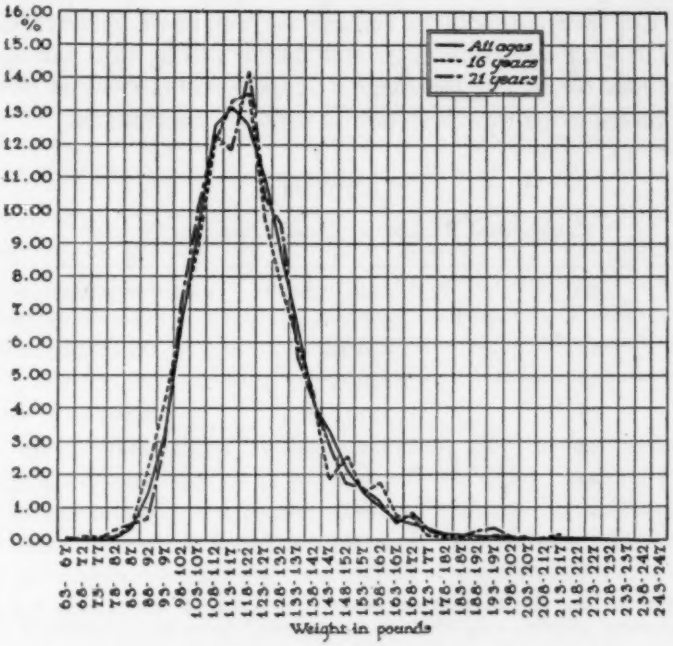

FIG. 3. DISTRIBUTION CURVES OF WEIGHT FOR COLLEGE WOMEN

Growth in Weight. In weight, as in height, the college women show no increase between 16 and 21 years of age (Table 8). This means that in college women cessation of growth in weight occurs several years earlier than in other women of our population. The reason for this may be that they have experienced acceleration of growth in weight as well as in height during their pre-college years; but one wonders whether it is biological for young women to show no gain in weight from 16 to 21 years of age, or whether their weights have been influenced by voluntary regulation of diet. On this question our data give no conclusive in-

formation, but the fact that in none of the eight colleges do the women show any gain in weight is suggestive that this phenomenon is practically universal if not biological.

Comparative Weights of Young American Women. In order to compare the weights of these college women with the weights of the women in the medico-actuarial group, the average weight of the shoes and clothing of young women, as determined above, was deducted from the weights given in the medico-actuarial tables. This correction probably is less than it should be because the weight of women's clothing in 1910 to 1912 was probably greater than it was in 1930, but since we have no data concerning the weights of shoes and clothing at that time, we are forced to use this correction as the only one available.

TABLE 10

Comparative Weights of Young American Women

AGE	COLLEGE WOMEN	MEDICO-ACTUARIAL DATA *
16	120.04±.45	115.03±.23
17	119.85±.19	120.12±.18
18	120.72±.15	122.09±.11
19	121.03±.18	124.86±.09
20	121.74±.27	124.11±.07
21	120.73±.36	124.71±.06
All ages	120.69±.09	123.54±.05

* Corrected for weight without shoes or clothing by subtracting 2.49 pounds from the mean weights with clothing as computed from medico-actuarial data.

In Table 10 the comparative weights of the college women and the women applicants for life insurance, corrected in the above manner, are shown. At 16 years of age, the college women are 5.01 ± .50 pounds heavier than the women of the life insurance group, but by 17 years of age the college women have begun to fall behind in weight, a tendency which continues through each of the succeeding ages covered by this study. At 19 years of age, the college women are 3.83 ± .20 pounds lighter than the women of the life insurance group, a difference which remains practically constant through the ages of 20 and 21 years. From this table it is evident that these relative changes in the weights of the

groups are due to the fact that college women fail to gain in weight after 16 years, while the other women continue to gain weight until 19 years of age.

Doubtless various factors have contributed to these differences in the weights of the groups, but probably one of the most important is that in recent years it has been stylish to be thin. The relative weights of the group at 16 years of age show that in the pre-college years the college women have gained in weight more rapidly than the other group, and it is reasonable to suppose that had no other factors been introduced, the effect of this early acceleration would have continued during these early years of adult life, just as it did with the men. By 19 years of age the weights of both groups have become stabilized but at this age the college women weigh 121.03 pounds as compared to 124.86 pounds for the women of the life insurance group.

Variability of Weight with Age. The variability of weight with age, as measured by the standard deviation, is from 16.71 ± .13 pounds in the 19 year old group to 17.99 ± .19 pounds in the 20 year old group. The partial standard deviations of weight with height held constant vary from 15.49 ± .12 pounds in the 17 year old group to 16.71 ± .13 pounds in the 19 year old group. These differences are statistically significant.

"Normal" Variability. Tables 2 to 7 show for each inch in height of each age group the number of cases, the mean weight with its probable error, and the standard deviation and coefficient of variability of individual cases from the mean. From such data the so-called standard tables of weight for age and height have been prepared. In groups which contain more than fifty cases the probable errors of the means are sufficiently small to render the data highly dependable. For such groups the coefficients of variability range from about 11 per cent to 15 per cent. In using "standard tables" of weight according to age and height, it is common practice to consider 10 per cent above or below average as the "normal" range of weight. Such figures as the above, however, indicate that it is most unreasonable to consider all cases which vary 10 per cent, or even 15 per cent, from the mean, as necessarily abnormal in weight. In fact, in any normal distribution approximately one-third of all the cases will vary more than one standard deviation from the mean. In other words, in weight data such as these for women approximately one-third of all the cases will be 13 or more per cent

above or below average. Furthermore, 5 per cent of the cases in a normal distribution will vary two or more standard deviations, in this case 26 per cent, from the mean. Certainly some definition of "normal variability" other than the 10 to 15 per cent used at present should be determined.

Body Build. Davenport's index of body build, $\frac{\text{weight} \times 1000}{\text{height}^2}$ shows a slight, though hardly significant, increase in college women from 16 to 18 years of age (Table 11). For the women of the life insurance group

TABLE 11

Comparative Body Builds of Young American Women *

AGE	COLLEGE WOMEN	MEDICO-ACTUARIAL DATA
16	29.47	30.12
17	29.54	31.09
18	29.76	31.32
19	29.68	31.89
20	29.86	31.75
21	29.72	31.96

* These indices of body build have been calculated according to Davenport's formula: $\frac{\text{wt.}}{\text{ht.}^2} \times 1000$, and represent the indices of the groups as a whole and not the means of the indices of the individuals in the groups.

this index shows an increase up to 19 years of age, but at every age it is significantly above the index for the college women. This means that the college women are of slighter body builds than the women from whom the life insurance data were compiled.

Correlations between Height and Weight. The coefficients of correlation (r) between height and weight are shown for the various age groups and for all ages taken together in Table 8. The range of these correlations is from $+.3922 \pm .0094$ to $+.4398 \pm .0123$, but none of the differences between age groups is significant. However, each of these correlations for women is significantly lower than the corresponding correlation for college men.

Comparison of the Weights of College Women with Medico-Actuarial Standards. The average weights for age and height, as given in the medico-actuarial tables for women, are used as standards in most

TABLE 12

Smoothed Average Weights—College Women—(Medico-actuarial Weights in Parenthesis)

HEIGHT	AGE					
	16	17	18	19	20	21
4 feet- 8 inches	96 (102)	97 (103)	97 (104)	97 (105)	97 (106)	97 (107)
4 feet- 9 inches	98 (104)	99 (105)	100 (106)	100 (107)	100 (108)	100 (109)
4 feet-10 inches	101 (106)	102 (107)	103 (108)	103 (109)	103 (110)	103 (111)
4 feet-11 inches	104 (108)	105 (109)	106 (110)	106 (111)	106 (112)	106 (113)
5 feet	108 (109)	109 (111)	109 (112)	109 (113)	109 (114)	109 (115)
5 feet- 1 inch	111 (111)	112 (113)	112 (114)	112 (115)	112 (116)	112 (117)
5 feet- 2 inches	114 (114)	115 (116)	115 (117)	115 (118)	115 (119)	115 (120)
5 feet- 3 inches	117 (117)	118 (119)	118 (120)	118 (121)	118 (122)	118 (123)
5 feet- 4 inches	120 (120)	121 (122)	122 (123)	122 (124)	122 (125)	122 (126)
5 feet- 5 inches	124 (124)	124 (125)	125 (126)	125 (127)	126 (128)	126 (129)
5 feet- 6 inches	127 (128)	127 (129)	128 (130)	128 (131)	129 (132)	129 (133)
5 feet- 7 inches	129 (132)	130 (133)	131 (134)	131 (135)	132 (136)	132 (137)
5 feet- 8 inches	132 (136)	133 (137)	134 (138)	135 (139)	136 (140)	136 (141)
5 feet- 9 inches	135 (139)	136 (140)	137 (141)	138 (142)	139 (143)	139 (144)
5 feet-10 inches	138 (143)	139 (144)	140 (145)	141 (146)	142 (147)	142 (148)
5 feet-11 inches	141 (148)	142 (149)	143 (150)	144 (151)	145 (151)	146 (152)
6 feet	144 (153)	145 (154)	146 (155)	147 (155)	148 (156)	149 (156)

college health and physical education work. Are these standards really satisfactory, was the question which prompted this study. Table 12 presents the smoothed average weights of the college women without shoes and clothing and, in parentheses, the standard medico-actuarial weights including shoes and clothing. The same smoothing process was used on the data for college women as has been described for college men(1).

From a comparison of these figures it is evident that the weights of the college women are uniformly lower than the corresponding weights given in the medico-actuarial table. In actual pounds these differences range from 0 pounds to 9 pounds and in percentages from 0 per cent to 6 per cent. In other words, certain girls, although of average weight according to the tables for college women, might be up to 6 per cent underweight according to the medico-actuarial tables. The weights of the largest proportion of the college women, however, fall in the center of the table where the percentage differences between these two tables are very small and certainly unimportant when considered in relation to an average coefficient of variability of 12 to 13 per cent for the group as a whole.

On the other hand, strange as it may seem, these medico-actuarial tables which include shoes and clothing become much less satisfactory as standards if the weights of the college women also include shoes and clothing. For example, a college girl 18 years of age, 5 feet 4 inches tall and weighing 122 pounds without shoes or clothing would be, according to the medico-actuarial tables, 1 pound, or less than 1 per cent, underweight; but, if she wore shoes and clothing of the average height and weight, her height would be 5 feet 6 inches and her weight 124 pounds, making her 6 pounds, or approximately 5 per cent underweight. In less central portions of the table, these differences become still greater. Hence, it seems that the medico-actuarial tables are reasonably satisfactory standards of weight for college women if the measurements of the college women do not include shoes and clothing but are from 5 to 10 per cent too high if shoes and clothing are included in the measurements. In the use of any of these standard tables, however, the possibilities of large normal individual variability from the mean must be kept in mind.

PHYSICAL DIFFERENCES BETWEEN WOMEN OF THE VARIOUS COLLEGES

In the process of analyzing these data correlation tables for height and weight were prepared for each age group of each college and the statistical constants derived from these correlation tables are shown for each college in Tables 13 to 20. A study of these indicates that there

TABLE 13

North Carolina College for Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	64.00±.12	119.84± .92	2.34±.08	18.41± .65	+.3505±.0437	183
17	63.70±.05	116.34± .38	2.03±.03	16.50± .27	+.3792±.0196	865
18	63.62±.05	116.53± .37	2.18±.04	16.01± .26	+.4183±.0191	850
19	63.74±.08	118.46± .56	2.23±.05	16.60± .40	+.4077±.0284	393
20	63.67±.15	117.81±1.07	2.28±.10	16.52± .76	+.4353±.0526	108
21	63.20±.15	117.24±1.85	1.56±.11	19.22±1.31	+.2935±.0881	49

TABLE 14

Cornell University Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	63.26±.19	127.24±1.39	2.09±.13	15.68± .98	+.4245±.0726	58
17	63.31±.07	123.80± .49	2.30±.05	16.58± .34	+.3990±.0246	530
18	63.46±.05	123.26± .69	2.32±.04	16.83± .26	+.4518±.0172	976
19	63.30±.06	122.41± .46	2.31±.04	16.68± .32	+.4643±.0215	607
20	63.35±.10	123.11± .79	2.40±.07	18.33± .56	+.4502±.0345	243
21	63.54±.21	125.16±1.37	2.44±.15	16.08± .97	+.3575±.0741	63

TABLE 15

Stanford University Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	64.44±.35	123.13±2.20	2.06±.25	13.02±1.55	+.4607±.1328	16
17	64.13±.18	123.09± .95	2.79±.13	14.85± .68	+.3632±.0558	110
18	64.46±.09	125.00± .69	2.29±.07	17.02± .49	+.4575±.0321	277
19	64.39±.08	123.39± .54	2.39±.06	16.39± .39	+.4987±.0250	412
20	64.49±.07	123.66± .59	2.15±.05	17.18± .42	+.4945±.0261	382
21	64.35±.10	121.92± .62	2.34±.07	15.29± .44	+.4912±.0310	273

TABLE 16

University of Wisconsin Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	63.89±.29	121.07±1.84	2.20±.20	14.23±1.28	+.3232±.1162	28
17	63.82±.09	120.58± .67	2.39±.06	17.44± .47	+.3859±.0326	310
18	63.94±.06	122.61± .47	2.34±.04	19.24± .33	+.3876±.0207	765
19	64.03±.07	120.44± .49	2.42±.05	16.08± .34	+.4248±.0247	499
20	64.02±.10	121.37± .69	2.46±.07	17.94± .49	+.4695±.0304	299
21	64.11±.11	120.99± .67	2.28±.08	14.00± .48	+.3841±.0410	197

TABLE 17

University of Minnesota Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	63.85±.25	127.50±1.98	2.60±.18	20.34±1.40	+.6516±.0561	48
17	63.51±.08	121.80± .59	2.17±.06	16.16± .42	+.4522±.0290	342
18	63.55±.05	121.02± .39	2.19±.04	16.23± .28	+.4196±.0199	777
19	63.55±.07	122.20± .56	2.22±.05	17.55± .40	+.4675±.0250	446
20	63.48±.08	121.41± .65	2.13±.06	17.10± .58	+.5279±.0272	252
21	63.27±.12	121.84±1.06	2.12±.09	18.56± .75	+.4387±.0684	139

TABLE 18

Smith College Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	63.88±.16	122.47±1.27	2.19±.11	17.37± .90	+.5035±.0546	85
17	64.31±.07	124.92± .47	2.27±.05	15.86± .33	+.4468±.0237	518
18	64.14±.05	123.36± .34	2.39±.04	16.12± .24	+.4413±.0170	1020
19	64.49±.06	124.56± .42	2.23±.04	15.94± .30	+.5045±.0198	643
20	64.00±.11	122.62± .82	2.29±.08	16.56± .58	+.3568±.0433	185
21	64.41±.31	122.50±1.92	2.64±.22	16.59±1.36	+.3967±.0975	34

TABLE 19

Michigan State Normal College Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	63.09±.14	119.09±1.15	1.92±.10	15.95± .81	+.4266±.0588	88
17	63.03±.07	119.36± .58	2.20±.05	17.83± .41	+.4352±.0262	437
18	63.00±.06	118.60± .48	2.29±.04	18.62± .34	+.3813±.0222	673
19	63.11±.08	118.92± .57	2.35±.05	17.43± .41	+.3586±.0287	420
20	63.20±.11	122.99± .94	2.45±.08	21.61± .67	+.4861±.0333	239
21	62.92±.12	120.66±1.13	2.34±.08	22.22± .79	+.4901±.0387	182

TABLE 20

University of Texas Women

AGE	MEAN		S. D.		$r_{wt.\ ht.}$	NO. CASES
	Height	Weight	Height	Weight		
16	64.05±.11	115.89± .84	2.25±.08	17.45± .59	+.4502±.0384	196
17	63.93±.07	115.05± .45	2.39±.05	15.90± .32	+.4314±.0231	564
18	63.73±.07	115.91± .45	2.47±.05	16.00± .32	+.3622±.0247	563
19	63.91±.08	115.06± .49	2.30±.05	14.91± .35	+.3817±.0282	418
20	64.09±.10	118.07± .70	2.19±.07	16.02± .49	+.3483±.0382	241
21	63.68±.13	115.44±1.02	2.21±.09	16.91± .72	+.2771±.0557	125
21	63.66±.12	114.69± .94	2.02±.09	15.34± .67	+.3272±.0548	121 *

* Excluding 4 cases of 21 years of age whose height or weight was more than 3σ from the mean of the group.

are significant differences both in height and in weight between the students of certain of these colleges. In order to make statistical comparisons of the women by colleges a single index of height, weight and body build seemed desirable. Such an index was obtained by computing the mean height, the mean weight and the mean body build of equal numbers of students who were 17, 18, 19 and 20 years of age from each college. The 16 and 21 year old groups were omitted because in some of the colleges the numbers of students in these age groups were very small.

Heights by Colleges. The average heights of these young women by colleges range from 63.09 inches for students of the Michigan State Normal college to 64.37 inches for women of Leland Stanford University (Table 21). Next in height to Stanford women are the women of Smith College, the other private institution of the group. Mosher(6) has shown that over a period of years the women of Vassar College are slightly taller than those of either Stanford or Smith. This superiority in height of the women of the private colleges is similar to our findings for college men and probably is due to the economic selection which the

TABLE 21

Comparative Physiques of Women in Certain Colleges *

	COLLEGE	HEIGHT		COLLEGE	WEIGHT
1.	Stanford	64.37	1.	Smith	123.87
2.	Smith	64.24	2.	Stanford	123.79
3.	Wisconsin	63.95	3.	Cornell	123.15
4.	Texas	63.92	4.	Minnesota	121.61
5.	North Carolina College for Women	63.68	5.	Wisconsin	121.25
6.	Minnesota	63.52	6.	Michigan State Normal	119.97
7.	Cornell	63.36	7.	North Carolina College for Women	117.29
8.	Michigan State Normal	63.09	8.	Texas	116.02

	COLLEGE	BODY BUILD †
1.	Cornell	30.68
2.	Michigan State Normal	30.14
3.	Minnesota	30.14
4.	Smith	30.02
5.	Stanford	29.88
6.	Wisconsin	29.65
7.	North Carolina College for Women	28.92
8.	Texas	28.40

* Students of 17, 18, 19 and 20 years of age with equal numbers from each age group.

† These indices of body build have been computed from mean heights and weights. The smaller indices indicate slighter builds.

fees of the private colleges introduce. That is, the students who attend them, on the average, have had better food and living conditions in childhood than the students of our state institutions, with the result that growth has been stimulated and greater than average stature attained. These differences in stature between the women of the various colleges do not seem to be due merely to an acceleration of growth in the earlier years because in none of the colleges do the women show significant growth in height after 16 years of age, the lowest age included in this study.

Weights by Colleges. The average weights of these young women by colleges range from 116.02 pounds to 123.87 pounds (Table 21). The order of the colleges by weight, as by height, shows that the women of Smith College and Stanford University stand at the head of the list. The smallest average weights are found among the women of the two southern colleges, North Carolina College for Women and the University of Texas.

Body Build by Colleges. Davenport's formula has been used to give an index of body build, the higher values indicating stockier builds and smaller values, slighter builds. From these indices (Table 21) it appears that the women of Cornell are relatively the heaviest and the women of the two southern colleges the slightest in relation to the height.

DIFFERENCES IN HEIGHTS AND WEIGHTS OF COLLEGE MEN AND COLLEGE WOMEN

By comparing the data presented in the previous report for college men(1) with the data here presented for college women, sex differences in physique may be studied.

Height. After 18 years of age, when growth in height has been completed for both sexes, the height of the men exceeds the height of the women by 5 inches but at 16 and 17 years of age, the sex differences are only 3.66 inches and 4.7 inches respectively. The increasing difference from 16 to 19 years of age is due to the fact that the college women have completed their growth in height by 16 years of age, while the men continue to grow for two or three years more (Table 22). These differences indicate that in comparison to the boys, the girls have shown an acceleration of growth prior to the age of 16. Boas(4) finds that this post-adolescence growth spurt reaches its peak at 11 to 12 years of age for girls and at 14 to 15 years of age for boys. The variability in height

TABLE 22

Sex Differences in Heights and Weights of College Students

A. Height

AGE	COLLEGE MEN MEAN HEIGHT	COLLEGE WOMEN MEAN HEIGHT	DIFFERENCE
16 years	67.48±.08	63.82±.06	3.66±.10
17 years	68.39±.03	63.69±.03	4.70±.04
18 years	68.72±.02	63.69±.02	5.03±.03
19 years	68.82±.02	63.86±.02	5.04±.03
20 years	68.79±.03	63.85±.04	4.94±.05
21 years	68.77±.04	63.74±.05	5.03±.06
All ages	68.68±.01	63.75±.01	4.93±.02

B. Weight

AGE	COLLEGE MEN MEAN WEIGHT	COLLEGE WOMEN MEAN WEIGHT	DIFFERENCE
16 years	133.70±.49	120.04±.45	13.66±.67
17 years	138.16±.21	119.85±.19	18.31±.28
18 years	141.09±.14	120.72±.15	20.37±.21
19 years	142.45±.15	121.03±.18	21.42±.23
20 years	144.05±.20	121.74±.27	22.31±.34
21 years	144.87±.28	120.73±.36	24.14±.45
All ages	141.65±.08	120.69±.09	20.96±.12

of the girls, as measured by the standard deviation, is less at each age (Table 8) than the variability in height of the boys(1).

Weight. The difference in the average weights of college men and college women for all ages taken together is 20.96 ± .12 pounds (Table 22). At 16 years of age, this sex difference is only 13.66 ± .67 pounds but from 16 to 21 years of age it increases annually until at 21 years it is 24.14 ± .45 pounds. Much of this weight difference is clearly due to the greater height of the men but, if one holds height constant for the sexes by comparing specific heights independently, one finds that there is still a sex difference in weight in favor of the men. For example, at 5 feet 6 inches in height the average weight of the men exceeds the

average weight of the women by 1 pound at 16 years, by 3 pounds at 17 years, by 4 pounds at 18 years, by 5 pounds at 19 years, by 6 pounds at 20 years, and by 7 pounds at 21 years; and at 5 feet 10 inches in height the average weight of the men exceeds the average weight of the women by 3 pounds at 16 years, 5 pounds at 17, 18, and 19 years, 6 pounds at 20 years, and 7 pounds at 21 years.

In weight, as in height, the college women show no increase during the age period covered by this study, 16 to 21 years, while the college men are showing a progressive annual increase in weight throughout the whole period. The variability in the weight of the college women is slightly less than the variability in the weight of the men but since the mean weights of the women are lower than the mean weights of the men, the coefficients of variability are slightly greater for the women than the men.

Body Build. The indices of body build for the college men and women show that the women are relatively stockier than the men at 16 years of age; that at 17 years of age they have the same type of body build; but that from 18 to 21 years of age the women are relatively slighter than the men.

The coefficients of correlation between height and weight are uniformly lower for the women than for the men. This is true of each age group as well as for the group as a whole.

SUMMARY

1. Age, height and weight data of 17,127 American college women between 16 and 21 years of age have been collected and analyzed.

2. The average height of these college women is $63.75 \pm .01$ inches; and the average weight, $120.69 \pm .09$ pounds.

3. No growth in either height or weight occurs in these women between the ages of 16 and 21 years.

4. The average increase in the height of 910 University of Minnesota women due to the wearing of shoes was found to be $1.73 \pm .01$ inches in September, 1930, and the average weight of their shoes and clothing to be $2.49 \pm .02$ pounds.

5. College women apparently are taller at least from 16 to 21 years of age than the women from whose heights and weights the medico-actuarial tables were computed. The weights of the college women,

however, are lower except at 16 years than the weights given for women in the medico-actuarial tables.

6. A comparison of a table of graded average weights of college women with the medico-actuarial table for women indicates that the medico-actuarial table will serve as a reasonably satisfactory standard of weight for college women if the college women are weighed and measured without shoes and clothing. However, if shoes and clothing are included, as they were in the life insurance examinations, the medico-actuarial tables become 5 to 10 per cent too high for college women.

7. The coefficient of variability indicates that approximately one-third of all these college women vary 13 or more per cent from the average, or so-called "standard," weight. This makes necessary a new definition of "normal" variability in weight.

8. A comparison of the heights and weights of the women from the various colleges shows that the students of the two private colleges, Smith and Stanford, are both taller and heavier than the women of any of the other institutions from which data were obtained.

9. A comparison of the statistical constants for women with those for men indicates that college men are taller and heavier than college women of the same age; that at 16 years of age the men are relatively slighter than the women but that from 18 to 21 years they become of stockier build than the women; and that the college women reach maximum growth in both height and weight several years earlier than do the men.

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THE DENTITION OF IDENTICAL TWINS WITH PARTICULAR REFERENCE TO AN IDENTICAL PATHOLOGICAL CONDITION

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Precisely fifty years ago the immortal Francis Galton(1) wrote: "Twins have a special claim upon our attention; it is that their history affords a means of distinguishing between the effects of tendencies received at birth and of those that were imposed by the special circumstances of their after-lives." The suggestion implicit in this statement was, as in so many other instances, destined to be but slowly realized, for it was not until the second decade of this century had almost completed its course that a certain lively scientific interest in twins began to manifest itself (2) (3) (4). Since the publication of Professor H. H. Newman's *Biology of Twins* in 1917 (3), a work which may be said to have laid the foundations of the subject preparatory to the study of twinning in man, an appreciable number of studies on various aspects of identical twins have appeared in the literature. The *dentition* of twins has, however, received a relatively little amount of attention, although gratifyingly enough it is a pleasure to be able to say that that little has been of an eminently high quality. Excellent studies of the dentition of twins have been made, from various aspects, by Riepenhausen(5), Goldberg(9), Korkhaus(7, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19), Minkoff(20), and others.

Goldberg's paper, which is a model of what such things should be, is particularly valuable for the reason that it makes abundantly clear, not only to practising dentists, but to biologists as a whole, the great practical benefits that may be derived from the study of twins. Thus, by a method of simple analysis Goldberg is able to separate the hereditary from the environmental factors which have been operative in giving to the individuals of each pair of twins their peculiar dentition at the time of analysis, and upon the basis of his results he is able to point a very pertinent moral with respect to orthodontic procedure.

Korkhaus' papers deal with a large variety of dental conditions, normal and abnormal, in both identical and fraternal twins. His observations are of great interest, for he demonstrates the fact that the most remarkable conditions of the jaw and teeth, their relations, tooth patterns, color, occlusion, and so on, are duplicated in identical twins with a degree of likeness as to be almost indistinguishable.

Minkoff's paper (20) gives an excellent introductory account of the various statistical matters relating to twinning, its frequency, distribution, and significance. Minkoff then reports the result of his examination of 31 pairs of identical twins, on whom he measured the dimensions of the jaws and the more usual anthropometric facial diameters. The work is admirably carried out, and the results, as was to be expected, show remarkable likenesses for all cases examined. These results are compared with the findings for fraternal twins, and the kinds and degree of difference or likeness evaluated.

FAMILY HISTORY

The general conclusion arrived at by the other observers, who have recorded their observations on twins and who are referred to in the bibliography, is that identical twins display in both the normal and abnormal characters of their dentition a likeness as near to unitary identity as it is possible for two individuals to show. In the present study I am able to add yet another singularly interesting and altogether surprising fact to the increasingly large store of information now available relating to the biology of twins. This consists in the report of an exceptional pathological condition affecting the same teeth in the same way in a pair of identical twins, whose dentitions in this as in all other respects are remarkably alike.

Unfortunately very little information of a genetically useful nature could be elicited from the parents of these twins. Such information of a general nature as I have been able to obtain (from the father of the twins) is as follows:

The father of the twins was the second in order of birth of eleven children of whom the seventh and eighth in order of birth were identical male twins, one of the latter dying in infancy. His senior and most junior siblings were females, the other eight siblings being male. The youngest girl, according to my informant, was an "unwanted" child and suffered from a general arrest of development, dying in her fourth year. The first-born eldest sister has three children, in order of birth: female, and two males. Mr. B., the father of the male twins here reported upon, married in the early twenties, his wife was some years his junior. Both are of Russian Jewish origin. The twins were their first born. They have had no other children. Mr. B.'s third sibling has married

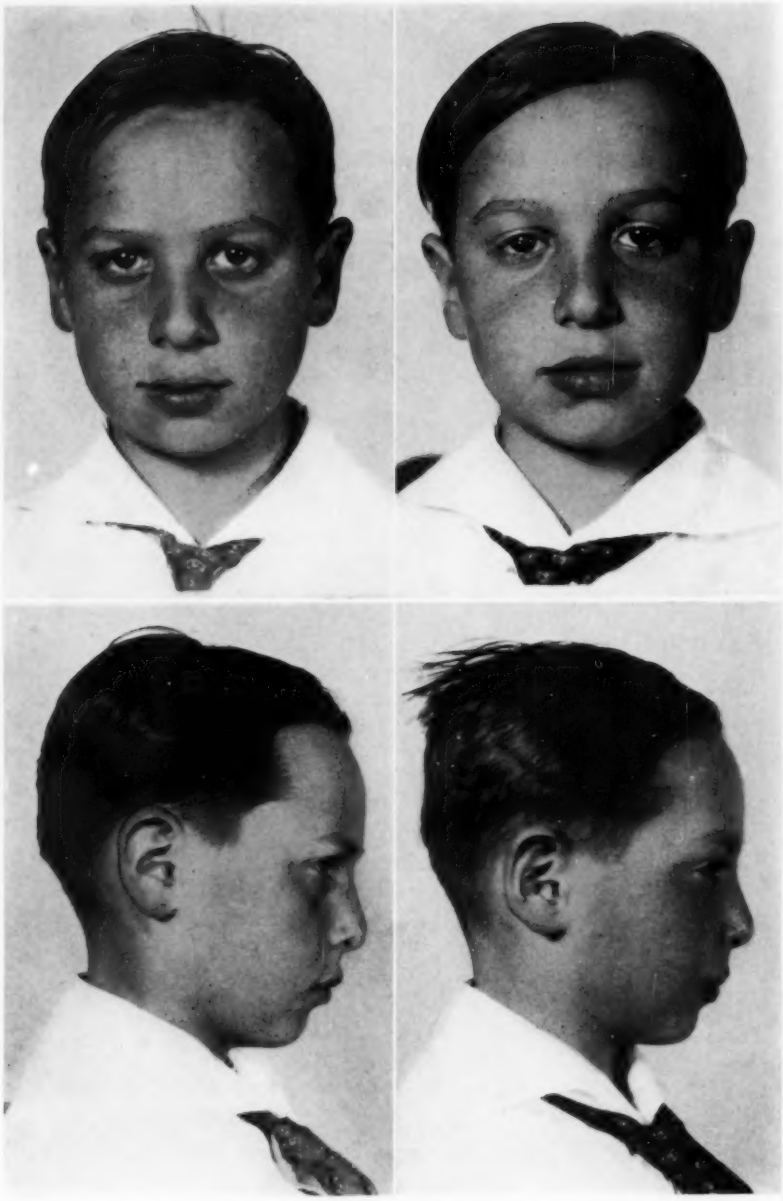

FIG. 1. FRONTAL AND RIGHT LATERAL VIEWS OF
D. (LEFT) AND (G. (RIGHT)
These views show the twins at 8 years and 3 months of age.

and has three children, in order of birth: two females and one male, the fourth sibling died in infancy. The fifth has married and has two children, one male and one female; the sixth has one child, a female. His seventh sibling who was one of a pair of male twins, whether identical or fraternal is not known, has only one daughter. The eighth sibling who was the brother twin of this pair died in infancy. The ninth and tenth siblings are unmarried, and the eleventh, as we have already noted died in her fourth year.

Mrs. B., the mother of the twins, is the first born of two children, her sibling, a male, is unmarried. Her grandmother had twelve children but no twins. Mrs. B.'s father's cousin (whether the paternal or maternal branch of the family she knows not) had identical twins.

DATA ON THE TWINS

The male twins, (see Fig. 1), who will hereafter be referred to as G. and D. were born at 7.30 on the morning of December 26, 1924, G. was born first and D. a few minutes later. D., according to his father, has always been bigger than G.

Such physical data as I have been able to obtain are given in Table 1 from which the degree of physical likeness between D. and G. may to some extent be judged.

TABLE 1

Data on the Identical Twins D. and G.

CHARACTER	D.	G.
General		
Type Delivery	Normal—10 hours	Normal—10 hours
Birth Weight	6 lbs. 5 oz.	5 lbs. 3 oz.
Feeding	Breast and Bottle 9 mos.	Breast and Bottle 9 mos.
Feeding	Orange Juice 3rd mo.	Orange Juice 3rd mo.
Feeding	Cod Liver Oil 1st yr.	Cod Liver Oil 1st yr.
Feeding	Cereal 3rd mo.	Cereal 3rd mo.
Feeding	Vegetable 5th mo.	Vegetable 5th mo.
Feeding	Egg Yolk 6th mo.	Egg Yolk 6th mo.
Feeding	All bottles stopped at 1 yr.	All bottles stopped at 1 yr.
Feeding	No difficulty in feeding	No difficulty in feeding
Feeding	No sensitivity to foods	No sensitivity to foods
Appetite	Fair	Fair
Bowels	Regular	Regular
Congenital Diseases	None	Enlarged heart. Left auricle systolic murmur
Contagious Diseases	None	None

CHARACTER	D.	G.
Other Diseases	Slight Bronchitis in 5th yr.	None
Other Diseases	Freq't colds until 6th yr.	Freq't colds until 6th yr.
Operations	Tonsilectomy at 2 yrs.	Tonsilectomy at 2 yrs.
Operations	Adenoidectomy at 2 yrs.	Adenoidectomy at 2 yrs.
Developmental History		
Held head up	6 months	6 months
Sat with support	7½ months	7½ months
Sat alone	8 months	8 months
First tooth	Left Central 7 mos.	Left Central 7 mos.
Teeth at 1 year	Eight	Eight
Stood alone	12 months	12 months
Spoke more than 5 words	14 months	14 months
Spoke sentences	18 months	18 months
Bowels trained	12 months	12 months
Bladder trained	12 months	12 months
Kindergarten	5th year	5th year
Anthropometric Data	At 8 yrs. 52 days	At 8 yrs. 52 days
Weight	79 pounds	68 pounds
Total Height	54.75 inches	53.25 inches
Sitting Height	660 mm.	660 mm.
Stomo-Omphalial Ht.	280 mm.	280 mm.
Omph-Symphyseal Ht.	144 mm.	111 mm.
Thelio-Omphalial Ht.	184 mm.	166 mm.
Acromial Breadth	275 mm.	274 mm.
Bi-Lateral Chest Diameter	200 mm.	200 mm.
Bi-Lateral Abdominal Diam.	197 mm.	194 mm.
Thor. Expirat. Girth	693 mm.	640 mm.
Norm. Breathing Girth	680 mm.	670 mm.
Ant. Post. Chest Diam.	160 mm.	152 mm.
Ant. Post. Abdo. Diam.	175 mm.	175 mm.
Thor. Inspira. Girth	723 mm.	700 mm.
Waist Girth	640 mm.	635 mm.
Bi-Thelial Diam.	154 mm.	143 mm.
Iliospinal Breadth	195 mm.	194 mm.
Iliocristal Breadth	206 mm.	205 mm.
Total Arm Length	427 mm.	410 mm.
Upper Arm Length	242 mm.	230 mm.
Lower Arm Length	185 mm.	180 mm.
Hand Length	153 mm.	141 mm.
Palm Breadth	66 mm.	63 mm.
Head and Face		
Maxim. Length	170 mm.	163 mm.
Maxim. Breadth	142 mm.	142 mm.
Glabella-Inion Diam.	170 mm.	163 mm.
Max. Circumf.	514 mm.	508 mm.

CHARACTER	D.	G.
Glab.-Inion Arc.	340 mm.	340 mm.
Sub-Cranial Length	190 mm.	190 mm.
Tragion-Vertex Ht.	72 mm.	72 mm.
Bi-Front-Molon Breadth	93 mm.	93 mm.
Bi-Zygomatic Breadth	122 mm.	111 mm.
Bi-Auricular Breadth	102 mm.	101 mm.
Bi-Mastoid Breadth	111 mm.	111 mm.
Sagittal Arc	300 mm.	280 mm.
Transverse Arc	345 mm.	340 mm.
Sub-Nasion Trich. Ht.	120 mm.	120 mm.
Phy. Sup. Fac. Ht.	62 mm.	62 mm.
Morph. Phys. Fac. Ht.	169 mm.	169 mm.
Frontal Ht.	71 mm.	73 mm.
Eye Breadth	31 mm.	40 mm.
Eye Ht.	35 mm.	25 mm.
Form	Long Oval	Long Oval
Interpupillary Diam.	55 mm.	53 mm.
Iris	Light Brown	Light Brown
Conjunctiva	Healthy white-blue	Healthy white-blue
Ear Breadth	34 mm.	32 mm.
Ear Ht.	57 mm.	61 mm.
Nose Breadth	33 mm.	31 mm.
Nose Height	46 mm.	47 mm.
Nose Length	19 mm.	18 mm.
Nasal Bridge Height	10 mm.	10 mm.
Form	Moderately flat	Moderately flat
Nostrils	Oblique (moderately)	Oblique (moderately)
Upper Lip Height	8 mm.	7.5 mm.
Upper Lip Breadth	54 mm.	48 mm.
Lower Lip Height	11 mm.	11 mm.
Lower Lip Breadth	53 mm.	46.5 mm.
Teeth Form	Square	Square
Teeth Color	1 Justi*	1 Justi*
Jaws		
Lower Jaw Height	33 mm.	32 mm.
Lower Jaw Length	101 mm.	84 mm.
Lower Jaw Breadth	108 mm.	98 mm.
Maxillary Height	13 mm.	10 mm.
Skin Color	Light Olive	Pale White
Hair Color	Light Brown	Light Brown
Hair Character	Straight	Straight
Eyebrows	Thin—Broad	Thin—Broad
Eyelashes	Long	Long
Handedness	Right	Left
Hair Whorl	Clockwise	Clockwise
Palmar Patterns	Identical	Identical

* Justi sample shade holder, H. D. Justi & Son, Philadelphia.

From these data it will be observed that the environmental and developmental history of the twins has been identical except for the fact that the younger of the two was born with an enlarged heart which has always yielded a consistent left auricular systolic murmur. Physically the older individual has always maintained his slight initial advantage in both weight and stature over the younger, but according to the father, G., the younger, possesses greater resistance than D. and is physically equally as strong, although the somewhat broader appearance of D. generally causes him to be assumed the stronger. Such differences as may be observed in Table 1 between D. and G. are generally in favor of D., but with the exception of Total Height, these may almost all be ascribed to the greater deposition of superficial fat in D. For the rest, the measures are really remarkably alike. (Chance of getting two like combinations in any two characters in man is 2×2^{24} or 1 in 32 million cases(*22*)).

According to the father the twins are temperamentally "very much alike." G., however, is more reasonable and tactful than D., whilst D. is, on the other hand, more truthful than G. Apparently G. performs the equation of the all-or-none principle more satisfactorily than the perfunctorily more honest D.

The father informs me that they are somewhat jealous of one another, though extremely fond of each other as well. Whenever he chastises one the other is pained and cries in sympathy.

Another interesting observation made by the father is that each boy exhibits a strong cyclothymic tendency, that is to say, each has a complementary cycle of excitement and calm or depression. These cycles are of about six months duration each. When D. is in the calm stage G. will be in the excited stage, and *vice versa*. When one lags behind in school the other progresses ahead, and so on.

DENTITION OF THE TWINS

And now for the raison d'être of this paper. In Fig. 2 I have reproduced the x-ray pictures of D. and G. the pictures of D. being placed above the pictures of the same teeth of G. so that a detailed comparison may be made. It should be borne in mind when viewing these pictures that the films were made in the arbitrary manner of the radiologist, that is to say, they were taken in no very definite plane, although, as may be seen from the pictures, the images compare fairly well. The

FIG. 2. X-RAY VIEW OF THE MAXILLARY SERIES OF TEETH OF D. (UPPER ROW) AND G. (LOWER ROW) COMPARED
See text for description.

x-rays were made on the 6th of February, 1931, that is, when the twins were six years and one and a half months of age. From the reproduction of these films seen in Fig. 2 the reader will have an opportunity of judging for himself the almost uncanny likeness between the two dentitions. The only differences to be observed are artefacts in the form of fillings. Caries at first began fairly symmetrically and then developed asymmetrically and have now, at the time of writing, returned to a symmetrical distribution in both individuals. The x-rays were taken during the period of asymmetry and when caries had not yet attacked the teeth of G. At the time of writing, as I have already noted, caries seems to have attacked the same teeth in both individuals and in almost the same situations.

In looking over the views of the teeth in Fig. 2 the reader should bear in mind the fact that G.'s head was probably tilted a little more forwards and downwards than was D.'s head when the films were made. This would account for the slightly greater perpendicular extension of the view of G.'s teeth as compared to the slightly more postero-oblique view of D.'s teeth.

Now beginning with D. in the first row at *a*, the upper left first permanent molar will be observed in a state of partial eruption, its relation to the second deciduous molar and to the developing permanent premolars should be noted and compared with the view of the same teeth, *a'*, in G. It will be seen that in respect to state of development, density, and relationships of the teeth there exists a similarity amounting almost to identity between these two dental groups. In actuality these words hold good for the complete dentition of both individuals, and with even greater force upon the basis of the extremely fine measurements which have been made of these dentitions and which will be discussed later in this paper.

In *b* the first deciduous molar with the second permanent molar above it is seen, next is seen the deciduous canine with the permanent canine high above it, then comes the deciduous lateral incisor with the permanent lateral incisor superiorly. Compare with *b'* and note particularly the form of the pulp in the canine and incisor in each individual. Note too the almost identical state of development and eruption of the teeth.

In *c* the right portion of the view in *b* may be seen showing the permanent and deciduous canines, the permanent and deciduous lateral incisors and the erupted permanent central incisor. Compare with *c'*

and note that the central incisor in D. *c* appears to be more fully erupted than in G. *c'*, and that the slight overlapping of the lateral by the central incisor in G. *c'* is due to the less advanced state of eruption of the central as compared with the same tooth in D. *c*. Note the remarkable similarity in the shape and size of the teeth and the form of trabeculisation in the alveolar body.

In *d* a portion of the left central incisor is seen, also the right permanent central, the distal angle of which is seen slightly overlapping the deciduous lateral incisor; note that in G. *d'* owing to the less advanced state of eruption of the same tooth the overlapping is not so pronounced. Note too, for an illustration of the arbitrary manner in which the x-rays of these teeth were taken the difference in the relative position of the upper central incisors and the diastema between them in the two views seen in G. *e'* and G. *d'*. Altogether however, as I have already had occasion to remark, these views were very satisfactorily taken, although they were made without any reference to possible future study. For the remaining teeth in this view we may turn to D. *e*.

In D. *e* a portion of the right central incisor may be seen, as we have already noted, overlapping the deciduous lateral; above, in the maxilla, the permanent canine is seen resting above and anterior to the permanent lateral and first premolar crowns; in the upper right corner is seen the crown of the second pre-molar, and below the first and second deciduous molars the distal angle of the first and the mesial angle of the second displaying ex-carious cavities which have been filled. In G. *e'* the view seen was taken a little more towards the lateral plane than in D. *e*. G. *e'* displays no evidences of caries, but in all other respects these views look as if they were taken from the same individual.

Now we arrive at what we have already referred to as the raison d'être of this paper. It is all seen in the views of D. *f*. and G. *f'*. Looking at D. *f*. we see the first permanent premolar situated above the first deciduous molar, higher up and to the right is to be observed the second permanent premolar situated fairly high in the maxilla above the second deciduous molar. But what does the second deciduous molar show? First, an exceptional resorption of its distal roots and of a portion of its crown. Second, the absorbed portion of the crown has been invaded by the erupting permanent first molar which has grown appreciably downwards and forwards into it, the mesial angle of the first permanent molar lodging in the excavated basin of the deciduous tooth whilst the distal

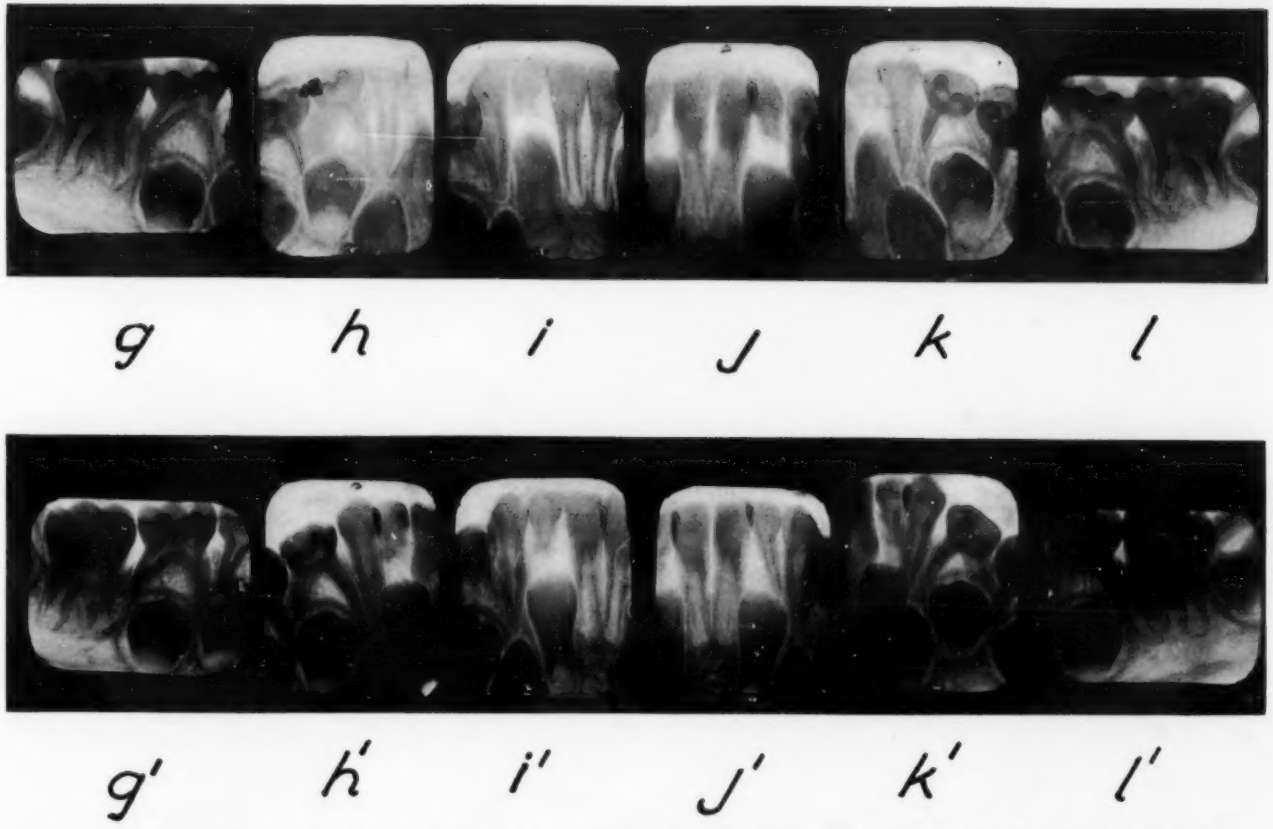

FIG. 3. X-RAY VIEW OF THE MANDIBULAR SERIES OF TEETH OF D. (UPPER ROW) AND G. (LOWER ROW) COMPARED
See text for description.

unresorbed wall of its enamel cap embraces the mesio-lingual cusp of the permanent molar.

This condition is perfectly duplicated in the twin G. as may be seen from Fig. 2 G. *f'*, and this it is which is so truly remarkable. The condition, it will be admitted, would be remarkable in itself as an occurrence in any individual, but its exact duplication in a set of twins endows it with an interest of paramount importance. For here is to be observed a pathological condition in which the pressure of an erupting permanent tooth upon a proximally situated deciduous tooth has caused the premature resorption of the distal roots of that tooth and the invasion of its body in a peculiar manner by the permanent tooth, eventually leading to the premature loss of the deciduous tooth—the whole process taking place in the same way in the two individuals in an astonishingly similar manner, down, in fact, to the smallest detail. The nature of the factors producing this total effect, or the degree of their complexity, cannot, in the present state of our knowledge, possibly be resolved. The assessment, however, of the relative parts played by nature and nurture or heredity and environment in the production of the condition described in the twins D. and G. presents little if any difficulty whatever. In fact the conclusion is irresistible that the condition described represents naught else than the genotypic expression of an inherited developmental tendency inseparably linked with the same factors as have given these two individuals, as we shall soon see, a dentition and a dental arch form which is in every respect indistinguishably similar. Nurture or environment cannot have played any other than a purely incidental, if any, part in determining the course of events the partial development of which I have described and which are seen in Figures 2 D. *f.* and G. *f'*.

That the factors responsible for this condition in the one child should have operated in so like a fashion in the other child leaves the writer utterly amazed. For we are not here dealing with a normal but with a *pathological* group of conditions subject to innumerable possibilities of development; even in identical twins one would not, even in one's most sanguine moments, expect to see what amounts to an almost absolute identity in all respects in the form of an extremely complex pathological condition. One would, on the other hand, expect to see a fair number of variations in the form of the condition. The condition, exhibited in the case of these twins is, therefore, the more remarkable for the extraordinary similarity of its form in the two individuals.

FIG. 3. X-RAY VIEW OF THE MANDIBULAR SERIES OF TEETH OF D. (UPPER ROW) AND G. (LOWER ROW) COMPARED
See text for description.

An examination of the x-ray views in Figure 3, which shows the teeth of the mandible or lower jaw in D and G, will reveal, as in the teeth of the upper jaw, the fact of their marked similarity.

In Figure 4 I have reproduced a map of the superimposed upper or maxillary dental arches of G. and D. made from casts the impressions for which were taken two and a half months before the x-rays of the condition I have already described were made, that is to say, when the twins were 5 years and 11 months of age. Before describing this and the succeeding maps, however, it would perhaps be advisable to say a few words with respect to the method of making them; for more complete information the interested reader may be referred to a paper published in December, 1931(23). The impressions for a cast of the dentition are taken in relation to the orbito-porion plane, a plane determined by the superior tragial points and the orbitalia. Casts are poured in stone and then oriented by means of a Stanton dental pantograph, in the *occlusal plane,* which may be defined as a horizontal plane relative to which every maxillary tooth not a molar extends below as far as the corresponding mandibular tooth extends above it. When this plane has been achieved the outlines of the teeth are projected by surveying the buccal and lingual surfaces of the teeth just above the gum—the "gum outline." Mesially and distally the survey is made of the greatest contour of the tooth. The grooves, cusps, and incisal edges are projected and the *tooth centroid,* which is the centre of the gum outline, determined and in its turn projected. The *centroid of the denture,* which is the geometric centre of the combined tooth centroids is then found and registered upon the map; this, in the maps, is seen as the point between the vertical and horizontal axes. The theoretical axis of symmetry of the denture is finally determined by the method of least squares, and the essential corrections made by means of a special protractor. The axis of symmetry is represented by the vertical axis seen in the maps.

The maps of the maxillary and mandibular dentures seen in Figures 4, 5, 6, and 7, have all been oriented in relation to one another by means of the centroid and axis of symmetry, of the denture, thus making possible an exact comparison between the two dentures.

Allowing in all the maps for the inevitable instrumental and instrumentalist's errors in the making of them it will be seen that in almost all respects they show an identity in the form, structure, and relations of the teeth compared which is truly remarkable.

In Figure 4 the maxillary series of G., solid lines, are compared with the same series in D., dotted lines. It will be seen from this map that D., who is physically the more developed of the twins, had at the time the casts were made, already lost the two upper central incisors. The teeth were in fact lost some time in January, 1931, shortly before the x-rays were taken. It is, however, to be noted that G. lost his two upper

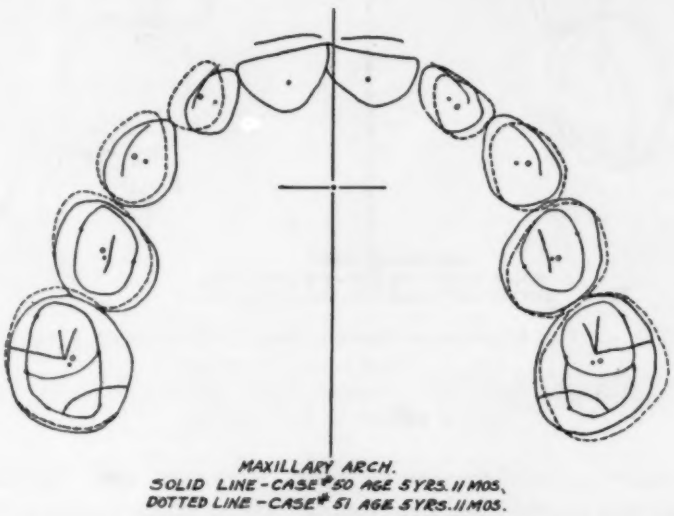

FIG. 4. THE MAXILLARY DENTAL ARCH OF D. (DOTTED LINES) AND G. (SOLID LINES) COMPARED
Note that D has lost his central incisors whereas G. still retains them.

centrals approximately five weeks after D. had lost his, and shortly after the x-rays were taken. The permanent upper centrals were reported as fully erupted in both individuals on June 5, 1931. The reader will observe the remarkable similarity in the form and structure of the teeth, as shown by the outlines of the teeth themselves, of their grooves, and cusps, and their relation to one another. Note too the almost identical situation of the tooth centroids.

Figure 5 represents the mandibular series of teeth at the same age as the above. Here the lower central incisors are present in D. as well as in G.; thus the reader may better judge the relation between the two dentitions in this region by observing the form, orientation, and position

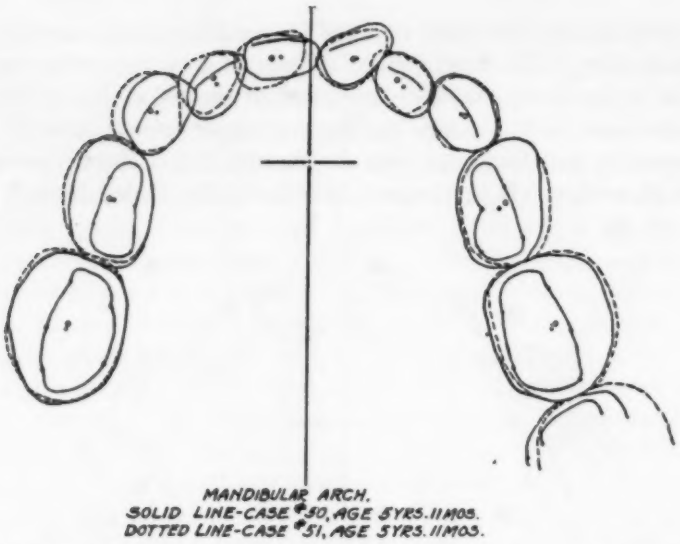

FIG. 5. THE MANDIBULAR DENTAL ARCH OF D. (DOTTED LINES) AND G. (SOLID LINES) COMPARED
Note the erupting first permanent molars and rotation of the central incisors on the right side.

of the incisal edges of the anterior teeth. Note particularly the identical relations between the tilted right central incisors which happen to occupy an aberrant position in the jaw. Note that the first permanent molar on the right side is in a similar stage of eruption in both individuals. Note too the amazingly symmetrical likeness of pattern in the molar teeth.

In Figure 6 is seen the map of the maxillary series of teeth of the twins made exactly two years after the preceding ones, namely, when they were 7 years and 11 months of age. Here the permanent incisors are seen fully erupted, the deciduous canine is still in place and so is the first deciduous molar, the second deciduous molar on the left side having been lost in both children in July, 1931, whilst the right second deciduous molar was lost at the same time in the case of D. but in G. was lost some five months earlier, namely in February. Note that the first permanent molars have erupted to the same extent in both individuals and that the diastema between the permanent molar and the deciduous first molar is precisely the same in both cases. Cusps, grooves, ridges, incisal edges, and tooth centroids are almost indistinguishable in both individuals with the exception of the right lateral incisor in G. which has undergone a

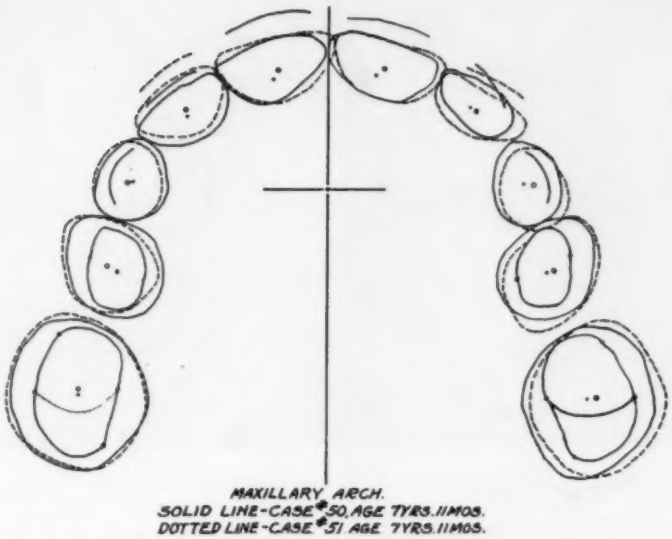

FIG. 6. THE MAXILLARY ARCH OF D. (DOTTED LINES) AND G. (SOLID LINES) COMPARED, TWO YEARS AFTER THE PRECEDING FIGURES, AT 7 YEARS AND 11 MONTHS
The only difference to be observed here is the slight rotation of the right lateral incisor in D.

slight rotation and thus shows an aberrant relation of its incisal edge when compared with the same tooth in D. With this exception the relations of the teeth are almost indistinguishably alike.

Figure 7 represents a map of the mandibular series of teeth. Here, too, in all respects the teeth are remarkably alike, even to a rotation of the lateral incisors on their long axes, with the exception that in D. the rotation has been clockwise and in G. counterclockwise, a difference which does not appear to me to be extremely significant, unless mirror imaging of movement can here be held to play some part. In this respect a fact of possible significance is that D. is left-handed and G. right-handed. The hair-whorls in both individuals run clockwise.

In Figure 8 will be seen a photograph of the casts from which the first described maps, shown in Figures 4 and 5 were made. The casts of D.'s dentitions are on the reader's left and of G.'s on the reader's right. It will be observed that the dentition of D. is in a slightly more advanced stage of eruption than the dentition of G. D., it will be seen,

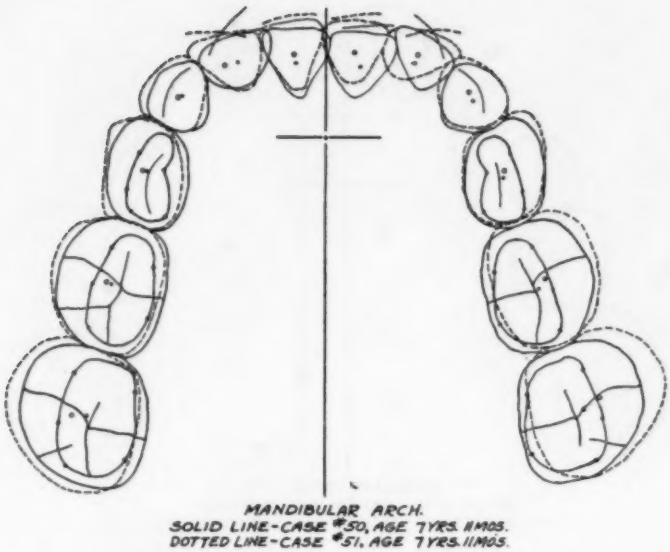

FIG. 7. THE MANDIBULAR ARCH OF D. (DOTTED LINES) AND G. (SOLID LINES) COMPARED, AT 7 YEARS AND 11 MONTHS
Note the rotation of the lateral incisors in both individuals, clockwise in D. and counterclockwise in G.

has already shed his upper central incisors whereas G. still retains them; also note that the lower right first permanent molar is in a slightly more advanced stage of eruption in D. than G. Note too, the slightly greater degree of overlapping of the left lower lateral incisor by the central incisor in G. than in D. For the rest these models are quite indistinguishable. Note the great similarity in the form of the rugae. The dimensions of the dental arches at 5 years and 11 months are given in Table 2.

From these figures it will be seen that there is but the most insignificant difference in the dimensions of the dental arches between the twins —invariably in favor of D. All these measures were taken at the most distal points between the gum outlines of the teeth in question, the maximum length being determined from the incisive point to the midpoint of a line drawn tangent to the distal surface of the second deciduous molars.

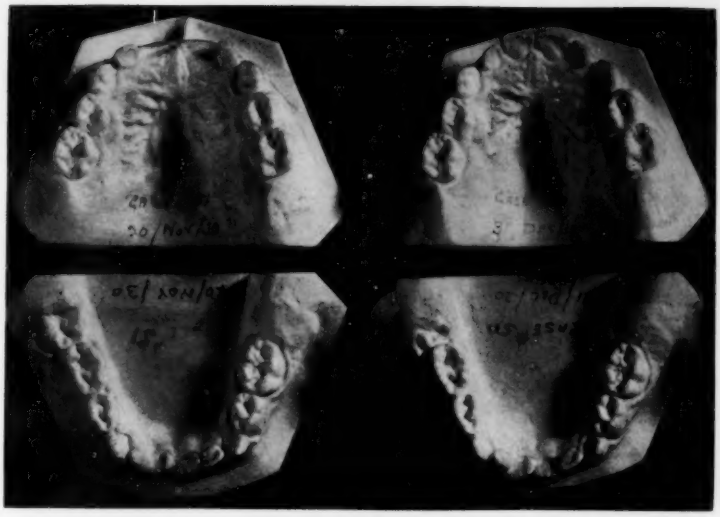

FIG. 8. CASTS OF THE DENTITION OF D. (ON THE READER'S LEFT) AND G. (THE READER'S RIGHT) AT 5 YEARS AND 11 MONTHS

The maps in Figs. 4 and 5 were made from these casts. Note the remarkable similarity in the form of the rugae.

FIG. 9. CASTS OF THE DENTITION OF D. AND G. FROM WHICH THE MAPS IN FIGS. 6 AND 7 WERE MADE

TABLE 2

Dimensions of Dental Arches at 5 Years and 11 Months

	D.	G.	DIFFERENCE IN FAVOR OF D.
Maxillary Arch			
Maximum D. at 2nd Molar	47.8 mm.	46.8 mm.	1.0 mm.
Maximum D. Length	28.2 mm.	27.9 mm.	0.3 mm.
Maximum Bi-Canine D.	33.9 mm.	32.5 mm.	1.4 mm.
Bi-Lat. Incisor D.	23.5 mm.	21.4 mm.	2.1 mm.
Bi-First Molar D.	40.0 mm.	39.3 mm.	0.7 mm.
Palatal Height	13.8 mm.	12.7 mm.	1.1 mm.
Mandibular Arch			
Maximum D. at 2nd Molar	44.2 mm.	43.8 mm.	0.4 mm.
Maximum D. Length	26.8 mm.	26.4 mm.	0.4 mm.
Bi-Lat. Incisor D.	18.5 mm.	17.9 mm.	0.6 mm.
Bi-Canine D.	28.0 mm.	27.2 mm.	0.8 mm.
Bi-First Molar D.	35.4 mm.	34.1 mm.	1.3 mm.

TABLE 3

Dimensions of Dental Arches at 7 Years and 11 Months

	D.	G.	DIFFERENCE IN FAVOR OF D.
Maxillary Arch			
Max. D. at 1st Perm. Molar	53.1 mm.	52.0 mm.	1.1 mm.
Max. Length	35.0 mm.	34.7 mm.	0.3 mm.
Bi-Lat. Incisor D.	31.2 mm.	30.0 mm.	1.2 mm.
Bi-Canine D.	38.3 mm.	37.5 mm.	0.8 mm.
Bi-1st Decid. Molar D.	43.0 mm.	42.3 mm.	0.7 mm.
Palatal Height	13.0 mm.	12.9 mm.	0.1 mm.
Mandibular Arch			
Max. D. at 2nd Perm. Molar	53.7 mm.	50.8 mm.	2.9 mm.
Maximum Length	37.3 mm.	36.7 mm.	0.6 mm.
Bi-Lat. Incisor D.	22.2 mm.	20.7 mm.	1.5 mm.
Bi-Canine D.	29.9 mm.	29.4 mm.	0.5 mm.
Bi-1st Decid. Molar D.	35.9 mm.	35.6 mm.	0.3 mm.
Bi-1st Perm. Molar D.	44.6 mm.	43.8 mm.	0.8 mm.

In Figure 9 a photograph of the casts taken two years later when the twins were 7 years and 11 months of age is shown. D.'s models are on the reader's left and G.'s on the right. The extraordinary resemblance between these two dentitions are even more remarkable than in the earlier set. With the exception of the rotated lower lateral incisors, which have already been described, these models are indistinguishably similar. The dimensions of these dental arches are given in Table 3.

Thus, it is seen that the form and dimensions of the dental arches of these twins are extraordinarily alike.

SUMMARY

1. The dentition is described of a set of white male identical twins, aged 5 years and 11 months, with particular reference to an unusual pathological condition.

2. The dentitions of the twins, by means of a mathematically exact mensurative analysis, are shown to be as nearly alike in the two individuals as it is possible for any two things to be.

3. Apart from the indistinguishable likeness of the form of the teeth, their crown patterns, grooves, ridges, orientation, relations, state of eruption, and calcification, a pathological resorption of the upper right second deciduous molar is described together with an invasion of the resorbed area by the first permanent molar—a series of conditions which have taken place in precisely the same way in each twin.

4. These conditions are considered to be entirely genotypic, affording a remarkable confirmation of the unitary nature of the developmental processes which are operative in uniovular (as these twins undoubtedly are) identical twins.

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THE SPECIFIC GRAVITY OF THE HUMAN BODY[1]

BY EDITH BOYD, M. D.

INTRODUCTION

The large amount of work already done on the specific gravity of the human body indicates that in general specific gravity is below 1 during deepest inspiration, above 1 during deepest expiration, and between the two during quiet respiration but usually above 1, that the values for children tend to be lower than those for adults, and that those for well-nourished, healthy persons are lower than those for emaciated, ill persons. These findings are in accord with the common observations that all persons tend to float in water when air is inhaled and to sink when air is exhaled, that the air in the chest during quiet respiration is hardly sufficient to keep the body afloat, that children appear to have less difficulty in keeping afloat without careful regulation of breathing than adults, and that obese individuals float without careful regulation of their respiration.

It became important in the course of a study of surface area to have more accurate estimates of these changes than are given in the literature. Beginning with the references in Vierordt ('06), the literature was searched for data consisting of individual case records which could be re-analyzed statistically. A fairly extensive hunt yielded 787 individual values[2] for specific gravity on subjects ranging in age from 2 fetal months to 60 years. For 598 subjects the specific gravity was determined by measuring the amount of water displaced by the body (the

[1] From the Institute of Child Welfare and the Department of Anatomy of the University of Minnesota.

[2] In some of the studies several determinations of specific gravity were made on the same subject. If they were made in succession, their mean was considered as a single determination. If they were made at a subsequent time when weight had changed, each determination was considered as a separate value of specific gravity.

water displacement method) and for 189 by weighing the body both in and out of water (the method of hydrostatic weighing). The readings were made on 205 cadavers and 582 living persons during all possible phases of respiration, namely: quiet respiration, quiet inspiration, quiet expiration, deepest inspiration, deepest expiration, and the mean of the last two, mid-respiration. The following brief reviews of all the available articles containing original observations give the method used, phase of respiration, character of the subjects, and summary values of specific gravity. The discussions of the technical problems involved have not been reviewed since they may be found in most textbooks of physics and since I have had no experience with them.

REVIEW OF LITERATURE

Robertson, in 1757, bribed 10 "middling sized men . . . for the most part very thin and slim made persons" to duck under water in his tank measuring 78 x 30 x 30 inches. The values for specific gravity calculated from his data range from 0.800 to 1.002. These values are lower than those obtained by subsequent workers, even for deepest inspiration. Robertson himself was not satisfied with the results and complained of the uncoöperativeness of his subjects, who seemed more interested in the bribe than in the experiment.

Sömerring (1844) stated that the specific gravity of the whole body was 1.059, but he made no statement as to method or subjects used.

Valentin (1850), without stating the technic used, reported the volume of a newborn female weighing 1.77 kg. as 1.733 liters, giving a specific gravity of 1.021.

Littré and Robin (1865), in their revision of the *Nysten Dictionnaire de Médecine* reported under *Pesanteur* that a man of ordinary constitution with a height of 172 cm., a weight of 64.25 kg., and a water displacement of 63.5 liters had a specific gravity of 1.011. A second man, described as more obese than robust, with a height of 175 cm., a weight of 78 kg., and a water displacement of 75.2 liters, had a specific gravity of 1.010. (If the weight and volume were correctly reported, the specific gravity should be 1.037.) They also stated that a forced inspiration increased the volume 3 to 4 liters. A woman with a height of 158 cm., a weight of 46.45 kg., and a volume of 46 liters had a specific gravity of only 1.009. This description is followed by the name *Ch. Robin* in parentheses. I have been unable to locate any work published separately by Robin on this subject.

Krause (1879), without stating the technic used, reported that the average specific gravity of the adult body in quiet respiration after a deep expiration was 1.055 and in the absence of air from the lungs and intestines it was 1.129.

During the course of his study of surface area and body weight relations, Meeh (1879) measured the volumes of 12 men and boys by water displacement during either deepest inspiration and deepest expiration or in a *willkürlicher* position of respiration. He stated that Professor von Vierordt made the study possible by having two volumeters constructed, one for children and one for adults. They consisted of zinc cylinders with attached graduated glass tubes for reading the

water level. The specific gravity of the 9 persons from 6 to 46 years of age, who could control their breathing properly, ranged during deepest inspiration from 0.959 to 1.059 and during deepest expiration from 1.005 to 1.122. For 8 persons ranging in age from 6 years to 66 years, who were measured during *willkürlicher* respiration, the specific gravity ranged from 0.978 to 1.079. Meeh also found that the differences between the volumes during deepest inspiration and deepest expiration were, with one exception, less than the vital capacity as measured by a spirometer.

Subsequently, in 1895, Meeh determined the volumes of the parts of the body on 4 dead infants and 10 living persons (8 males and 2 females) ranging in age from 12 to 60 years. The volumes of the major regions were measured in a large wooden volumeter, the smallest parts in two small tin volumeters, and the parts of the extremities of the infant cadavers in a graduated glass cylinder. All measurements on the living were taken during quiet (*gewöhnlicher*) respiration. The values for specific gravity calculated from Meeh's data for the dead infants ranged from 1.018 to 1.053, and for the living persons from 0.946 to 1.071 and did not show any increase with age.

Zuelzer (1884) determined the specific gravity volumetrically, using a tank with a connected glass measuring tube for reading the water level. The readings were taken during both deepest inspiration and deepest expiration, with the subjects breathing through a mask. The average mid-respiration value for young men was about 0.970. The lowest value, 0.926, was obtained for a 38 years old fat man measuring 172 cm. in height, 101 kg. in weight, and 109 liters in volume.

In 1894 Lahmann ('06) used a tank with an attached glass rod on which to read the water levels. The tank contained a built in bench for the subject to sit on. The body was submerged to the chin and the readings taken during deepest expiration. The head volume was calculated from its circumferences. The specific gravity ranged in 10 men from 1.016 to 1.072, and in 7 women from 1.022 to 1.055. In 4 more or less ill persons the specific gravity was higher, ranging from 1.088 to 1.091.

Ziegelroth (1896), following the technic of Lahmann, determined by water displacement the specific gravity during deepest expiration of all the body except the head. He considered the head a sphere with a circumference equal to the mean of the occipito-glabellar circumference and the circumference passing around the vertex, ears, and hyoid bone. The specific gravity during deepest expiration of 22 adult men ranged from 1.013 to 1.069, with a mean value of 1.055. Ziegelroth found the difference between the volumes during deep inspiration and deep expiration to be about 3 liters.

Mies (1899) determined the specific gravity by water displacement 68 times on 28 adult prisoners in good physical condition, and by hydrostatic weighing 86 times on 74 boys and men ranging in age from 8 to 61 years. In the first method the volume was determined by weighing the water displaced by the body. His apparatus consisted of a cylindrical tank with an overflow pipe draining into a vessel standing on a scale. In the second method, the man was suspended by an especially constructed harness from a beam balance into a tank of water. In both procedures the subject breathed through a water-tight mask and readings were taken during quiet respiration. The values for the two groups ranged from 1.012 to 1.082 and they appeared to increase slightly with age.

Packard (1900) weighed hydrostatically 35 boys from 14 to 18 years of age. Their specific gravity ranged from 1.000 to 1.051, with a mean of 1.020. During complete submersion with lungs deflated, the hydrostatic weight increased 1 to 8 pounds. When the body was weighed with the nose out of water, inflation of the lungs lowered the weight an average of 1.3 pounds and deflation raised it an average of 6.33 pounds.

Wengler ('02) described a cylindrical tank with connected graduated tube to measure the displaced water. He had the subject hold his nose and breathe through a mouthpiece which was held in place by a rubber flap between lips and teeth. During quiet respiration 3 men had specific gravities of 1.042, 1.027, and 1.013, and 3 women 1.028, 1.020, and 1.019.

In 1906 Wengler devised a cylindrical tank with a weighted lid which rested in a groove filled with mercury. The glass measuring tube for reading the water level and the breathing tube were in the lid. The subject entered the tank, put the breathing tube in his mouth, held his nose and ducked under. The assistants lowered the weighted lid, which was swung on a pulley so that the subject could remove it if necessary. The levels read from the manometer had to be corrected according to resistance of the mercury and counter-weights on the lid. With the aid of two assistants, Wengler, who weighed 75.5 kg., found his own volume during quiet expiration to be 74.9 liters and his specific gravity 1.008. By correcting for the differences in level between the extremes of respiration, he estimated that his air-free volume was 71.76 liters giving a specific gravity 1.05. He stated that so far no other determinations had been made because the procedure caused considerable disturbance in his small household.

Sytcheff ('02) determined hydrostatically the volume of 103 child cadavers ranging in age from birth to 15 years. Gundobin ('12) reported Sytcheff's data in a condensed form as averages for several months of age in the first year, then for each year of age. Apparently Dr. Francis Benedict of Boston has the only copy of the original article in this country. He graciously loaned me his translation of the original dissertation which contains the individual case reports and description of the method used.

According to this translation Sytcheff, after carefully considering and testing both the volumetric and hydrostatic methods, decided the latter was more reliable. He adapted one small beam balance for infants under one year and another for older children. Both scales had a short arm with a suspended scale pan for the weights and a long arm with a suspended pan of iron wire netting large enough to hold the outstretched human body. The long arm was twice the length of the short arm. After weighing the body in air, the empty netting pan was submerged into a large tub by a lead sinker which weighed the same as the short arm weight pan. The body was then placed on the submerged netting pan and the scales balanced. Sytcheff gave a detailed description of checking the balance by sand and of correction factors for the netting pan and sinker. The cadavers under one year came from the Imperial Home for Foundlings and those over one year from the City Hospital in St. Petersburg (Botkin). Markedly exhausted subjects or those with tympanites were not used. The detailed table given in the translation is reproduced in Table 1.

TABLE 1

Volumes of Children's Bodies According to Age (After Sytcheff)

AGE	SEX	HEIGHT *cm.*	WEIGHT *gm.*	VOLUME *cc.*	SPECIFIC GRAVITY
Abortus 1 d.	M	40	1670	1620	1.031
Abortus 4 d.	F	41	1505	1470	1.024
Newborn	F	45	2097	2027	1.035
15 d.	M	52	2980	2906	1.025
15 d.	M	47	2512	2443	1.028
27 d.	M	53	2747	2688	1.022
1 to 2 mo.	M	55	3422	3356	1.020
1 to 2 mo.	M	59	3150	3101	1.016
1 to 2 mo.	M	54	3055	3055	1.000
1 to 2 mo.	F	51	2837	2793	1.016
1 to 2 mo.	F	55	3415	3386	1.009
2 to 3 mo.	M	52	2384	2289	1.042
2 to 3 mo.	M	54	3310	3262	1.015
2 to 3 mo.	F	60	3985	3946	1.010
2 to 3 mo.	F	57	3615	3585	1.008
3 to 4 mo.	M	56	3385	3321	1.019
3 to 4 mo.	M	55	3520	3461	1.017
3 to 4 mo.	M	59	3980	3903	1.020
3 to 4 mo.	F	56	3835	3771	1.017
4 to 5 mo.	M	59	4121	4037	1.021
4 to 5 mo.	M	58	4489	4417	1.016
4 to 5 mo.	M	60	4469	4390	1.018
4 to 5 mo.	F	60	5098	5050	1.010
4 to 5 mo.	F	58	4579	4460	1.027
5 to 6 mo.	M	63	5138	5033	1.021
5 to 6 mo.	M	61	5167	4889	1.057
5 to 6 mo.	F	62	4990	4812	1.037
6 to 8 mo.	M	63	6047	5860	1.032
6 to 8 mo.	F	62	5125	4948	1.036
6 to 8 mo.	F	63	5806	5628	1.032
8 to 9 mo.	M	65	5184	5176	1.002
8 to 9 mo.	F	65	6132	6054	1.013
9 to 10 mo.	M	64	5183	5092	1.018
9 to 10 mo.	M	66	6204	6075	1.021
9 to 10 mo.	F	70	6880	6803	1.011
10 to 11 mo.	M	66	6706	6635	1.011
10 to 11 mo.	M	72	7105	7102	1.000
10 to 11 mo.	F	68	7510	7441	1.009
10 to 11 mo.	F	70	6631	6505	1.019
11 to 12 mo.	M	69	6840	6817	1.003
11 to 12 mo.	M	70	7700	7682	1.002

TABLE 1—*Continued*

Volumes of Children's Bodies According to Age (After Sytcheff)

AGE	SEX	HEIGHT *cm.*	WEIGHT *gm.*	VOLUME *cc.*	SPECIFIC GRAVITY
11 to 12 mo.	F	70	7500	7375	1.017
1 to 2 yr.	M	69	7064	6874	1.028
1 to 2 yr.	M	70	8207	7993	1.027
1 to 2 yr.	M	82	6921	6807	1.017
1 to 2 yr.	F	74	8819	7696	1.146 *
1 to 2 yr.	F	79	9599	9588	1.001
1 to 2 yr.	F	68	8279	8212	1.008
2 to 3 yr.	M	80	9753	9614	1.014
2 to 3 yr.	M	79	9022	8971	1.006
2 to 3 yr.	F	78	8775	8666	1.013
2 to 3 yr.	F	91	9753	9614	1.014
2 to 3 yr.	F	85	9353	9237	1.013
2 to 3 yr.	F	91	9710	9446	1.028
3 to 4 yr.	M	96	12577	12519	1.005
3 to 4 yr.	M	96	12857	12507	1.028
3 to 4 yr.	M	98	13094	13034	1.005
3 to 4 yr.	M	89	12013	11700	1.027
3 to 4 yr.	F	96	14467	14229	1.017
3 to 4 yr.	F	88	11730	11605	1.011
4 to 5 yr.	M	92	13533	13432	1.008
4 to 5 yr.	M	93	14198	14191	1.000
4 to 5 yr.	M	104	13642	13047	1.046
4 to 5 yr.	F	97	12159	12079	1.007
4 to 5 yr.	F	94	11848	11845	1.000
5 to 6 yr.	M	102	17053	16679	1.022
5 to 6 yr.	M	100	10486	10399	1.008
5 to 6 yr.	M	102	13761	13539	1.016
5 to 6 yr.	M	105	15702	15693	1.001
5 to 6 yr.	M	98	11927	11551	1.033
5 to 6 yr.	F	97	10370	10221	1.015
5 to 6 yr.	F	104	14961	14510	1.031
6 to 7 yr.	M	102	15970	15786	1.012
6 to 7 yr.	M	108	17752	17634	1.007
6 to 7 yr.	M	106	15795	15155	1.042
6 to 7 yr.	F	107	15051	14831	1.015
6 to 7 yr.	F	108	12130	11932	1.017
7 to 8 yr.	M	102	18426	18318	1.006
7 to 8 yr.	M	121	17124	16715	1.024
7 to 8 yr.	M	117	16669	16564	1.006
7 to 8 yr.	F	114	16485	15891	1.037

TABLE 1—*Continued*

Volumes of Children's Bodies According to Age (After Sytcheff)

AGE	SEX	HEIGHT *cm.*	WEIGHT *gm.*	VOLUME *cc.*	SPECIFIC GRAVITY
7 to 8 yr.	F	111	15135	15069	1.004
7 to 8 yr.	F	101	15120	14478	1.044
8 to 9 yr.	M	110	15758	15145	1.040
8 to 9 yr.	M	104	15170	14590	1.040
8 to 9 yr.	F	120	19107	18746	1.019
8 to 9 yr.	F	118	18198	17529	1.038
8 to 9 yr.	F	122	19832	19751	1.004
8 to 9 yr.	F	113	12836	12446	1.031
9 to 10 yr.	M	123	19380	18542	1.045
9 to 10 yr.	M	119	15477	15415	1.004
9 to 10 yr.	F	111	17167	16627	1.032
10 to 11 yr.	M	132	21663	21462	1.009
10 to 11 yr.	M	131	21827	21082	1.035
10 to 11 yr.	M	130	19000	18403	1.032
10 to 11 yr.	F	133	24069	23308	1.033
10 to 11 yr.	F	127	18330	18156	1.010
11 to 12 yr.	M	118	17810	17505	1.017
11 to 12 yr.	M	138	21695	21287	1.019
11 to 12 yr.	F	131	25990	25331	1.026
12 yr.	F	135	21782	21332	1.021
15 yr.	M	145	36855	35940	1.025
15 yr.	M	141	30135	29432	1.024

* Omitted from calculations.

Jamin and Müller ('03) constructed a cylindrical tank containing a platform for the subject to sit on. Readings of water displacement in the tank were made from a connected glass manometer. They gave a summary table of previous work and their own values of specific gravity. The mean specific gravity during *willkürlicher* respiration for 19 healthy men ranging in age from 10 to 40 years was 1.007, and for 23 healthy young men, during deepest inspiration 1.003, during deepest expiration 1.044, and during middle respiration 1.017. For 11 sick persons, ranging in age from 20 to 63 years, the mean specific gravity was 0.992. For 2 healthy women the mean specific gravity was 1.002, apparently in *willkürlicher* respiration. In addition, since they wished to determine the specific gravity of patients who could not be totally submerged, they had both healthy and sick subjects sit in a tank with the water just to the chin line and read the increase in volume from the attached graduated glass rod. The body weight divided by this amount of displaced water they called the specific equivalent weight. The mean specific equivalent weight for 27 males ranging in age from 8 to 90 years was 1.095, for 26 females of the same age range 1.081.

Subsequently Müller and Seidelmann ('06) found normal soldiers had an average specific equivalent weight of 1.079, with a range from 1.040 to 1.120. Ill persons had a lower average of 1.074.

Seitz ('08), while studying the lay of the fetus in utero, determined by water displacement the specific gravity of 13 macerated and 27 non-macerated fetuses, ranging in length from 22 to 53 cm. The specific gravity increased from 1.040 to 1.055 and the state of the body did not seem to materially affect the values.

Jackson ('09) made this statement: "In the earlier months, the specific gravity of the embryo is very little over 1, though in later fetuses it reaches 1.04 or 1.05."

Wiemer ('10) obtained the volumes by water displacement, with the head held half out of water, on 65 normal children from 8 to 13 years of age, and on 68 scrofulous children of the same ages. The normal children had a ratio of weight to this partial volume ranging from 1.01 to 1.04, while the scrofulous children had a range of 1.003 to 1.050.

Oppenheimer ('12) determined the volume 50 times on 27 living infants by submerging them up to the chin in a cylindrical tank of water, and by calculating the volume of the head on the basis that it was a sphere with a diameter equal to the mean of the biparietal, fronto-occipital, fronto-suboccipital and mento-occipital diameters of the head. The amount of water displaced was read from a graduated glass rod connected to the tank by rubber tubing. The glass rod was so placed that the water level was at zero before the body was submerged. The specific gravity ranged from 0.940 to 1.045, with a mean of 0.992. To check the method of calculating the volume of the head, he determined the volume of the detached heads of 3 infant cadavers by water displacement and found the calculated volume was 7 per cent below the measured volume. In addition, the figures in one of his tables show a discrepancy of about 10 per cent between the calculated head volume and the measured head volume when the head was still attached to the body. Because of these discrepancies, he preferred the specific equivalent weight introduced by Jamin and Müller, which ranged from 1.218 to 1.399, with a mean of 1.315.

Kastner ('12) determined the volume 36 times on infant cadavers and 118 times on living children, most of whom were ill. He used a cylindrical zinc tank 70 cm. high, with an overflow pipe at 62 cm. The tank was filled to the level of the overflow pipe, the cadaver submerged, and the overflowing water collected in a measuring vessel by means of a drain and funnel. The living children were suspended into the water up to the chin and hair line of the neck by means of a harness on the chest and arms and a bandage at the ankles. The volume was of necessity determined at the deepest inspiration the child took while submerged. The head volume was determined graphically from a curve formed by plotting the head volumes of 30 infant cadavers against their horizontal head circumferences. The specific gravity for living children ranged from 0.883 to 1.244 and for cadavers from 0.897 to 1.180. The specific equivalent weights ranged for living children from 1.102 to 1.381 and for cadavers from 1.117 to 1.347.

The work of Kastner was instigated by Pfaundler ('12), who reviewed previous work and analyzed the technical difficulties in measuring specific gravity, especially those due to respiration. In addition he estimated the amounts specific gravity would be changed both by increasing or decreasing the total body weight of an infant 5, 10, or 20 per cent in either panniculus adiposus, muscle, water or

total ash, and by increasing or decreasing the volume of the body by 50, 100, or 300 cc. On the whole, he found that a change of 100 to 300 cc. in the air content of a 4 kg. infant would vary the specific gravity of the total body more than either a 20 per cent change in weight due to subcutaneous tissue, musculature, total ash, or a 10 per cent change due to water. An error in volume of 25 cc. would change specific gravity about 0.0060 units.

Subsequently Pfaundler ('16) determined the net volume of the body by an ingenious air pressure chamber, whereby he found the volume of the cadaver minus the air in the intestinal tract and lungs. The mean air-free specific gravity of fourteen infant cadavers was 1.143, in contrast to the mean value of 0.988 obtained on the same cadavers by water displacement. The average amount of gas in the body amounted to 404 cc., or 12.8 per cent of the total volume of the body.

Murlin and Hoobler ('13) determined the specific gravity of 5 male and 1 female infants, following the technic of Pfaundler. The values ranged from 0.973, in a normal 2 months old boy, to 1.118, in an atrophic 3 months old boy.

Barnum ('15), as a part of a study on the effect of gravitation on the presentation and position of the fetus, determined the specific gravity of 8 fetuses ranging in age from 5 fetal months to term. His method was to suspend the fetus from a beam balance in a salt solution. The specific gravity of the salt solution was so adjusted that the fetus was just supported by it. The fetus then had the same specific gravity as the solution. His 8 values, ranging from 1.037 to 1.054, are in close agreement with those obtained by Seitz.

Griffith ('15) determined by hydrostatic weighing the specific gravity on 46 fetuses which had not breathed. Five were macerated and the remainder were fresh fetuses. One fetus was a case of anencephalus and two were cases of hydrocephalus. In the others the specific gravity ranged from 1.032 at the second month to a maximum of 1.060 at 9 months. His values are similar to those obtained by Seitz and Barnum.

Spivak ('15) determined by water displacement the volumes of various regions of the body as well as of the total body on 15 boys and men. He had the subject step down into a narrow tank built with a connected glass manometer. After readings had been taken at various levels and the water was up to the subject's thyroid cartilage, the subject, without first taking a deep breath, held his breath and ducked slowly under. The values for specific gravity ranged from 0.016 to 1.049.

Bardeen ('20) reported two volume determinations, one on a 2 years old cadaver and the other on a 6 years old living child. For the latter the specific gravity was 1.025, since weight was 20.86 kg., volume 20.35 liters, and height 118.1 cm. For the 2 years old cadaver, the weight was given as 7.28 kg., the volume as 12.6 liters, and length as 83.8 cm., which would give a specific gravity of 0.577. Probably a typographical error occurred in reporting these values, because a 2 years old child measuring 83.8 cm. in length is not likely to have a weight of only 7.28 kg.

Mumford ('27) measured the specific gravity by hydrostatic weighing during deepest inspiration and deepest expiration of 80 boys from 13 to 18 years of age. The mean values for deepest inspiration, ranging from 0.975 to 0.982, did not show an age trend, while those for deepest expiration, ranging from 1.045 to 1.065, did show an increase with age as well as those for mid-respiration, ranging from

1.011 to 1.019. He noted that the younger boys had considerable difficulty in deflating the chest. In the appendix of his book there is a brief historical survey.

Zook ('31 and '32)[3] measured the volume of various regions of the body by gradually lowering the subject standing on a movable platform into a tank of water. The amount of water displaced by each section of the body was measured by a graphic recording device. Before submerging the head the subject was given a mask to breathe through. The readings over the chest region were taken during both deepest inspiration and deepest expiration. His subjects consisted of 95 boys from the University of Chicago High School, ranging in age from 5 to 19 years, and of 69 boys from the University of Chicago Settlement in the Stock Yards district, ranging in age from 6 to 15 years. Most of the data in both groups were for boys from 10 to 16 years of age. He found that the mean weights for each year of age of the University group were above those of the normal weight curve of Baldwin but fluctuated around the weight curve based on 1500 measurements of boys in attendance at the University High School. The weights of the Settlement group were considerably below those of the University standard, but fluctuated uniformly around the curve based on Baldwin's norm. The mean specific gravities for each year of age for the University and Settlement groups were not significantly different according to the graphic presentation. For the total group the smoothed mean specific gravities for each year of age from 5 to 19 years increased during deepest inspiration from 0.978 to 1.000, during deepest expiration from 1.027 to 1.080, and for mid-respiration from 1.002 to 1.040. Zook ascribed the age increase in part to percentage increase of muscle, bone and mineral content of the bones in the body, and in part to the inability of the younger boys to exhale completely. All the basic data of height, weight, volume of parts, dimensions, etc., were published in detail in the 1932 report. In addition, Zook described one apparatus for measuring specific gravity directly by means of a platform supported by buoyance tanks and a second apparatus for measuring volume of the head alone.

SELECTION OF DATA

Certain sets of data could not be used because individual case reports either were not given or were incomplete. For the data containing adequate information the specific gravities were plotted against both stature and age for each phase of respiration. Inspection of these graphs showed that the only reasonably consistent data were those of Seitz for stillborn infants, of Sytcheff for cadavers of both boys and girls, of Mies for boys and young men during quiet respiration, and of Zook for boys during deepest inspiration and deepest expiration and hence mid-respiration. All other series contained for corresponding

[3] Mr. Zook and Professor Freeman of the Department of Education, University of Chicago, kindly granted me the use of Mr. Zook's thesis before its publication in 1932.

phases of respiration both extremely high and extremely low values. Moreover, Sytcheff's values for cadavers [4] made a continuous progression on both body stature and age with the values obtained by Mies for boys and young men during quiet respiration (Figures 1 and 4). This seems reasonable, since respiration is usually quiet at the time of death. The chest comes to rest in a position of either quiet inspiration or expiration, usually in the latter due to relaxation of the muscles. As a result, the data on cadavers and on living persons during quiet respiration were combined and, for convenience, were designated specific gravity during quiet respiration.[5]

The selection for consistency reduced the usable data to those obtained on cadavers which had not been markedly affected by disease or on living persons in reasonably good physical condition. Also all usable data on the living were obtained with the person breathing through a mask, instead of voluntarily holding the breath while under water.

In summary, in the literature there were available for statistical analysis 444 case records containing usable data for specific gravity on subjects in reasonably good physical condition. Of these, 40 were for the prenatal period (Seitz), 240 for quiet respiration as defined above (Sytcheff [6] and Mies), and 164 for deepest inspiration, deepest expiration and mid-respiration (Zook).

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[4] For the postnatal period only Sytcheff's data contained values for both sexes. The differences between the statistical constants (namely: mean age, mean length, mean specific gravity and regression coefficients of specific gravity on both stature and age) for his male and female subjects were all less than the standard errors of the differences. Hence these data do not show any sex differences in specific gravity.

[5] The regression coefficients of specific gravity on stature for the three divisions of so-called quiet respiration data (namely: Sytcheff's 102 cadavers, Mies's 86 hydrostatic observations, and Mies's 52 volumetric observations) were 0.000032 ± 0.000046, 0.000115 ± 0.000075, and -0.000363 ± 0.000268 respectively. The differences between the three are not significant since the greatest difference is only 1.7 times its standard error. This substantiates the impression from the graphic analysis that the rates of increase in the three groups were not essentially different.

[6] One of Sytcheff's cases was omitted because its specific gravity of 1.146 was so far above all other comparable readings that some error in technic or recording must have occurred.

METHOD OF ANALYZING DATA

The values of specific gravity in these data for each phase of respiration were plotted against both body stature [7] (Figures 1, 2 and 3) and age (Figures 4, 5 and 6). In spite of high variability, specific gravity appeared to increase rectilinearly with both stature and age during each phase of respiration, except in the first few months of life when during quiet respiration they seemed to decrease slightly. The data were obviously inadequate for determining whether this were a real or merely an apparent decrease in specific gravity. As a result, the data for quiet respiration in the postnatal period were analyzed both for the period from birth to maturity (240 cases) and for the period from one year to maturity (201 cases).

The rectilinear relation of specific gravity to either stature or age within a given respiratory phase may be represented by the regression equation

$$y = a + bx, \qquad (1)$$

when y is specific gravity, x is stature or age, b is the regression of y on x, or regression coefficient, and a is equal to the mean of y minus the product of the mean of x and b.

The regression coefficient represents the amount the specific gravity increases on the average with each unit increase in either stature or age. The dispersion of specific gravity around the regression line was estimated by the standard deviation of y with x held constant, $\sigma_{y.x}$. The standard errors were calculated for both the regression coefficients and the standard deviations. The regressions of specific gravity on either stature or age during the various respiratory phases were tested for significant differences in the usual statistical manner by finding the ratio of the difference between any two regression coefficients and its standard error, when the standard error of the difference is equal to the square-root of the sum of the squares of the standard errors of the two co-

[7] Sytcheff and Seitz of necessity measured the stature of the cadavers in the supine position, while Mies and Zook measured the living boys and men standing. According to Palmer ('32), when the supine length is 110 cm. it is 1 cm. greater than standing height, but this difference has decreased to 0.6 cm. by 170 cm. of supine length. The calculations for study were completed before Palmer's study was published. Since specific gravity increases slowly with stature and is itself highly variable, I assumed this small progressive difference between supine and erect length would not have sufficient effect on the regression lines to justify the labor of recalculation.

efficients. The dispersion of specific gravity for each phase of respiration was tested for significance in like manner. The differences in the level of specific gravity in the various phases of respiration could have been compared statistically by the difference between the means of y if the stature or age range covering any two groups had been the same. Usually this was not the case, but the levels are obviously different. All the equations used in determining these constants by Pearsonian correlation technic were given by Dunn ('29).

RELATION OF SPECIFIC GRAVITY TO STATURE

The expressions representing the relation of specific gravity (G) to stature in centimeters (S) are:

for the prenatal period before respiration starts,

$$G = 1.03406 + 0.000365S; \qquad (2)$$

for quiet respiration in the total postnatal period,

$$G = 1.00373 + 0.000203S; \qquad (3)$$

for quiet respiration in the postnatal period after the first year,

$$G = 0.99721 + 0.000245S; \qquad (4)$$

for deepest inspiration in childhood and adolescence,

$$G = 0.93224 + 0.000337S; \qquad (5)$$

for deepest expiration in childhood and adolescence,

$$G = 0.97654 + 0.000466S; \qquad (6)$$

and for mid-respiration in childhood and adolescence,

$$G = 0.95431 + 0.000402S. \qquad (7)$$

The regression coefficients, b, and the standard deviations of specific gravity with stature held constant, $\sigma_{G.S.}$, and their standard errors are given in Table 2.

TABLE 2

Specific Gravity—Stature

RESPIRATORY PHASE	EQUATION	b	$\sigma_{G.S.}$
Before respiration	(2)	0.000365±0.000057	0.00339±0.00039
Quiet respiration	(3)	0.000203±0.000019	0.01290±0.00059
Quiet respiration after 1 yr.	(4)	0.000245±0.000028	0.01294±0.00065
Deepest inspiration	(5)	0.000337±0.000070	0.01278±0.00071
Deepest expiration	(6)	0.000466±0.000079	0.01442±0.00080
Mid-respiration	(7)	0.000402±0.000069	0.01271±0.00071

The regression lines calculated from these equations were drawn on the scattergrams for their respective phases of respiration in Figures 1, 2 and 3, with two parallel lines corresponding to plus and minus one standard deviation from the regression line. By definition, one-sixth of the specific gravities for the respective respiratory phase would be ex-

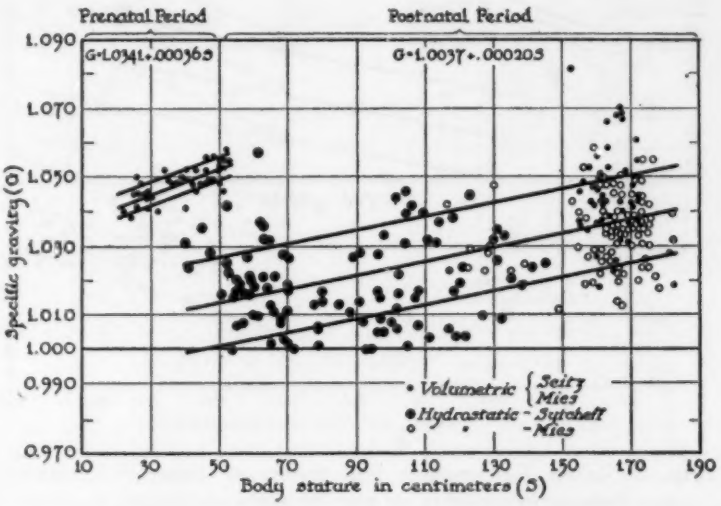

FIG. 1. SCATTERGRAM ILLUSTRATING THE RELATION OF SPECIFIC GRAVITY TO STATURE BOTH BEFORE RESPIRATION STARTS AND DURING QUIET RESPIRATION

The three short parallel lines are the regression line and the plus one and minus one standard deviation lines for prenatal life (Equation 2), and the three long parallel lines are those for postnatal life during quiet respiration (Equation 3). Two-thirds of the specific gravities during quiet respiration would be expected to fall within the three long parallel lines, and two-thirds of those for fetuses within the three short parallel lines.

pected to fall above the plus one standard deviation line, one-sixth below the minus one standard deviation line, and two-thirds between them. In order to demonstrate the effect of the extreme phases of respiration on specific gravity, the scattergrams and regression lines for the extremes of respiration (Figure 2) and their mean (Figure 3) are superimposed on the regression lines for quiet respiration and before respiration, as given in Figure 1.

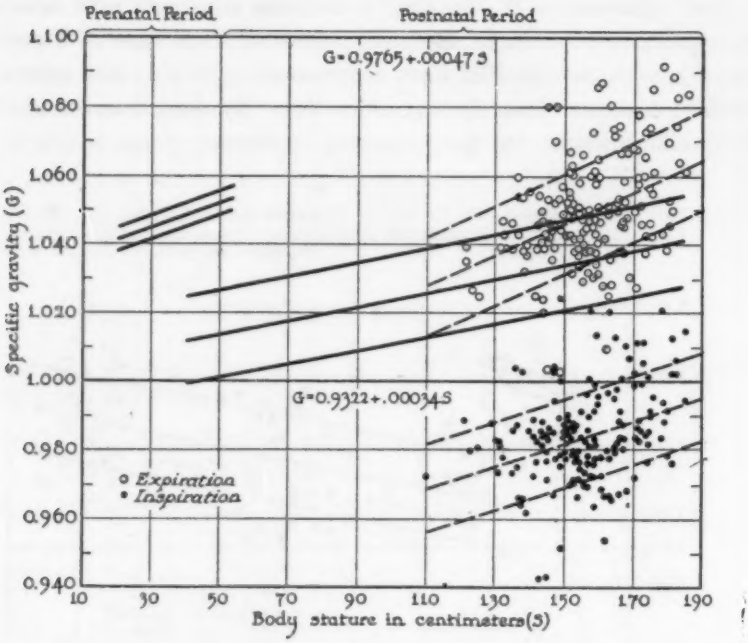

FIG. 2. GRAPH ILLUSTRATING THE EFFECT OF DEEPEST EXPIRATION AND DEEPEST INSPIRATION ON THE RELATION OF SPECIFIC GRAVITY TO STATURE DURING QUIET RESPIRATION

The solid lines are the regression line and the plus one and minus one standard deviation lines of before respiration and during quiet respiration from Fig. 1. The upper three parallel broken lines are the regression line and the plus one and minus one standard deviation lines for deepest expiration (Equation 6), and the lower three lines for deepest inspiration (Equation 5).

The values of specific gravity for the prenatal period and for the total postnatal period during quiet respiration calculated at 5 cm. intervals of body stature according to equations 2 and 3 respectively are given in Table 3.

The increase of specific gravity with each centimeter increase in stature, as measured by the regression coefficients (Table 2) and illustrated by the slope of the regression lines (Figures 1, 2 and 3), appeared to be greater in deepest expiration, mid-respiration and before respiration than in quiet respiration and deepest inspiration. However, the differences between the coefficient for prenatal life and those for all

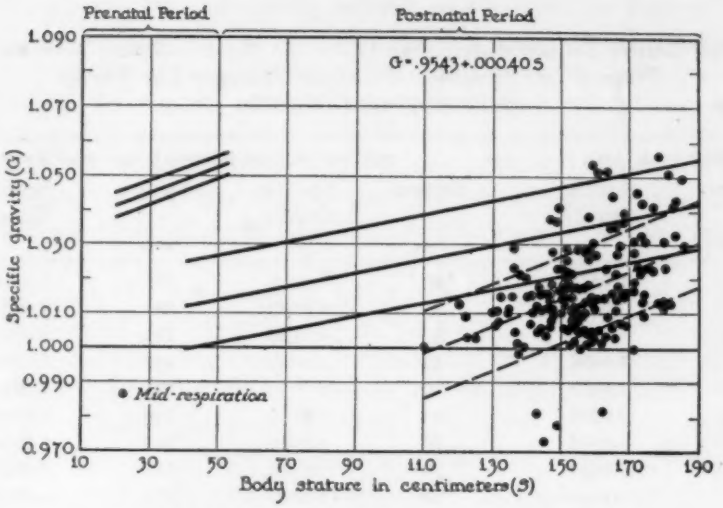

FIG. 3. GRAPH ILLUSTRATING THE EFFECT OF MID-RESPIRATION ON THE RELATION OF SPECIFIC GRAVITY TO STATURE DURING QUIET RESPIRATION

The solid lines are the regression line and the plus one and minus one standard deviation lines of before respiration and during quiet respiration from Fig. 1. The three parallel broken lines represent the regression line and the plus one and minus one standard deviation lines for mid-respiration (Equation 7).

phases of respiration in the postnatal period are not statistically significant except in the instance of quiet respiration, when the difference is 2.7 times its standard error. When the cases under one year of age are omitted from the quiet respiration group (Equation 4), the difference between the coefficients is only 1.88 times its standard error, indicating that such a difference could occur by chance 6 in 100 times. Hence, according to common statistical interpretation, the differences between the prenatal and postnatal increments of specific gravity with body stature are not significant. If more data were available, the apparent differences might very well prove to be significant.

Within the postnatal period the regression coefficients for deepest expiration and mid-respiration are significantly different from that for quiet respiration, the differences being respectively 3.25 and 2.76 times their standard errors. If the coefficient for quiet respiration after one year is used, the differences are 2.63 and 2.12 times their standard

TABLE 3

Specific Gravity Calculated According to Specific Gravity—Stature Formulas for Prenatal Life (Equation 2) and for Postnatal Life During Quiet Respiration (Equation 3)

PRENATAL LIFE		POSTNATAL LIFE DURING QUIET RESPIRATION			
Stature	Specific Gravity	Stature	Specific Gravity	Stature	Specific Gravity
cm.		*cm.*		*cm.*	
20	1.0414	40	1.0119	115	1.0271
25	1.0432	45	1.0129	120	1.0281
30	1.0450	50	1.0139	125	1.0291
35	1.0468	55	1.0149	130	1.0301
40	1.0487	60	1.0159	135	1.0311
45	1.0505	65	1.0169	140	1.0322
50	1.0523	70	1.0179	145	1.0332
55	1.0541	75	1.0190	150	1.0342
..	.....	80	1.0200	155	1.0352
..	.....	85	1.0210	160	1.0362
..	.....	90	1.0220	165	1.0372
..	.....	95	1.0230	170	1.0382
..	.....	100	1.0240	175	1.0393
..	.....	105	1.0250	180	1.0403
..	.....	110	1.0261	185	1.0413

errors, indicating that the differences could occur by chance only 1 and 3 times in 100, respectively. Usually such odds are interpreted to mean that the differences are not due to chance. In this instance they are probably due to the inability of the younger boys to completely exhale, noted by Zook and also by Mumford. This factor would give artificially low values for the younger boys and thus increase the slope of the regression lines for the deepest expiration and for mid-respiration. Attention is called to the fact that deepest expiration values for the shortest boys (Figure 2) fall within the normal zone of variability in specific gravity for quiet respiration. Also the standard deviation for deepest expiration is higher, but not significantly so, than that for any other respiratory phase in postnatal life (Table 2).

In short, as far as can be estimated from the available data, specific gravity increases at approximately the same amount with each centimeter increase in stature throughout the total developmental period, except as age affects the individual's ability to exhale, and after respiration starts the variability is essentially the same.

The general level of specific gravity, as illustrated in Figures 1, 2 and 3 and Table 3, is relatively high in the prenatal period, increasing from 1.041 at 20 cm. of stature to 1.052 at 50 cm. With the onset of respiration the specific gravity drops approximately 0.038 units, so that the specific gravity of the newborn, 1.014, is only slightly above that of water. From birth (50 cm.) to maturity (180 cm.) it increases only 0.026 units, which is less than the decrease due to onset of respiration. Since this increase of 0.026 units is only twice as great as the standard deviation about the regression line, 0.013, the upper sixth of the values for infants would be expected to fall within plus or minus one standard deviation about the regression line in the adult period and, conversely, the lower sixth of adult specific gravities would fall within plus or minus one standard deviation about the regression line in infancy.

Deepest inspiration in boys averaging 157 cm. in stature lowered specific gravity to an average level of 0.985 (Equation 5), which is 0.051 units below the value 1.036 calculated for the same stature from the quiet respiration formula (Equation 3). For 24, or 15 per cent, of the boys, specific gravity was slightly above 1, indicating that these boys would have difficulty in keeping afloat in fresh water. On the other hand, deepest expiration in the same boys raised the specific gravity to 1.050 (Equation 6), which is the same as the level reached by the end of the fetal period and is 0.014 units above the level during quiet respiration. The decrease due to deepest inspiration is 3.6 times as great as the increase due to deepest expiration, so the mid-respiration value 1.017 (Equation 7) is not equal to that of quiet respiration but is 0.019 units below it. The range in specific gravity from deepest inspiration to deepest expiration is 0.065 units, or 6.4 per cent, which is 2.5 times the increase from birth to maturity.

RELATION OF SPECIFIC GRAVITY TO AGE

The same general plan of analysis has been used for determining the relation of specific gravity to age, with the exception that the data for persons 25 or more years of age were omitted because adult stature had been reached and the data were insufficient for determining whether specific gravity is essentially stationary, increases, or decreases with age after adult stature is reached (Figure 4). This reduced the quiet respiration group to 215 cases.

The expressions representing the relation of specific gravity to age are:

for the prenatal period before respiration starts, when T equals age in lunar months,[8]

$$G = 1.03426 + 0.001788T, \quad (8)$$

or, when A equals age in years,

$$G = 1.03303 + 0.025307A; \quad (9)$$

for quiet respiration in the postnatal period from birth to 25 years,

$$G = 1.01612 + 0.001025A; \quad (10)$$

for quiet respiration in the postnatal period from 1 to 25 years,

$$G = 1.014197 + 0.001125A; \quad (11)$$

for deepest inspiration in childhood and adolescence,

$$G = 0.96368 + 0.001566A; \quad (12)$$

for deepest expiration in childhood and adolescence,

$$G = 1.01041 + 0.002871A; \quad (13)$$

and for mid-respiration in childhood and adolescence,

$$G = 0.98705 + 0.002218A. \quad (14)$$

The regression coefficients and the standard deviations of specific gravity with age held constant and their standard errors are given in Table 4.

TABLE 4

Specific Gravity—Age

RESPIRATORY PHASE	EQUATION	b	$\sigma_{g.A.}$
Before respiration	(9)	0.025307±0.003967	0.00340±0.00397
Before respiration	(8)	(0.001788±0.000329	0.00367±0.00042)*
Quiet respiration under 25 yrs.	(10)	0.001025±0.000095	0.01259±0.00061
Quiet respiration between 1 and 25 yrs.	(11)	0.001125±0.000122	0.01252±0.00067
Deepest inspiration	(12)	0.001566±0.000458	0.01321±0.00073
Deepest expiration	(13)	0.002871±0.000503	0.01451±0.00081
Mid-respiration	(14)	0.002218±0.000451	0.01303±0.00072

* For age in lunar months.

[8] The ages of the specimens measured by Seitz were calculated from the Scammon-Calkins ('23) age-length formula

$$T = 2.3 + \frac{2.5L}{28} + \frac{L^2}{784}$$

when T equals fetal age in lunar months and L equals crown-heel length in centimeters.

The regression lines calculated from these equations were drawn on the scattergrams for their respective phases of respiration in Figures 4, 5 and 6, with two parallel lines corresponding to plus and minus one standard deviation. By definition, one-sixth of the specific gravities for

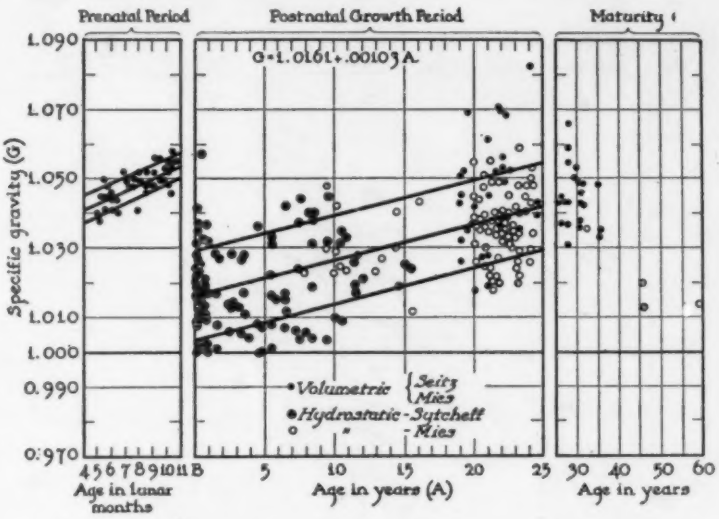

FIG. 4. SCATTERGRAM ILLUSTRATING THE RELATION OF SPECIFIC GRAVITY TO AGE BOTH BEFORE RESPIRATION STARTS AND DURING QUIET RESPIRATION

The three short parallel lines are the regression line and the plus one and minus one standard deviation lines for prenatal life (Equation 8), and the three long parallel lines are those for postnatal life during quiet respiration (Equation 10). Two-thirds of the specific gravities during quiet respiration would be expected to fall within the three long parallel lines, and two-thirds of those for fetuses within the three short parallel lines.

the respective respiratory phases would be expected to fall above the plus one standard deviation line, one-sixth below the minus one standard deviation line, and two-thirds between them.

The calculated values for prenatal life, according to Equation 8, and for quiet respiration in postnatal life, according to Equation 10, are given in Table 5.

The same general relations hold for specific gravity and age as for specific gravity and stature, except that the prenatal rate of increase is much more rapid than the postnatal rate in any phase of respiration. In

fact, the rate per lunar fetal month is approximately the same as per postnatal year. Within the postnatal period the rate of increase of specific gravity as measured by the regression coefficient is significantly higher in deepest expiration and possibly so in mid-respiration than in quiet respiration from birth to 25 years (Equation 10), since the dif-

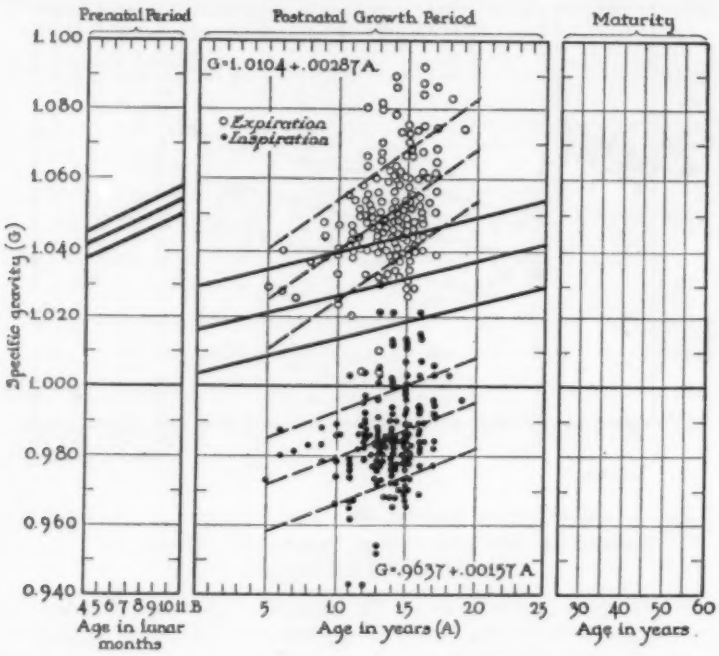

FIG. 5. GRAPH ILLUSTRATING THE EFFECT OF DEEPEST EXPIRATION AND DEEPEST INSPIRATION ON THE RELATION OF SPECIFIC GRAVITY TO AGE DURING QUIET RESPIRATION

The solid lines are the regression line and the plus one and minus one standard deviation lines of before respiration and during quiet respiration from Fig. 4. The upper three parallel broken lines are the regression line and the plus one and minus one standard deviation lines for deepest expiration (Equation 13), and the lower three lines for deepest inspiration (Equation 12).

ferences between the coefficients are, respectively, 3.61 and 2.59 times their standard errors. If the first year data are omitted from those for quiet respiration (Equation 11), the ratios of the differences between the coefficients to their standard errors are reduced only to 3.37

TABLE 5

Specific Gravity Calculated According to Specific Gravity—Age Formulas for Prenatal Life (Equation 8) and for Postnatal Life from Birth to 25 Years of Age During Quiet Respiration (Equation 10)

PRENATAL LIFE		POSTNATAL LIFE DURING QUIET RESPIRATION			
Age *lunar months*	Specific Gravity	Age *years*	Specific Gravity	Age *years*	Specific Gravity
5	1.0432	Birth	1.0161	13	1.0294
6	1.0450	1	1.0171	14	1.0305
7	1.0468	2	1.0182	15	1.0315
8	1.0486	3	1.0192	16	1.0325
9	1.0504	4	1.0202	17	1.0335
10	1.0521	5	1.0212	18	1.0346
..	.....	6	1.0223	19	1.0356
..	.....	7	1.0233	20	1.0366
..	.....	8	1.0243	21	1.0376
..	.....	9	1.0253	22	1.0387
..	.....	10	1.0264	23	1.0397
..	.....	11	1.0274	24	1.0407
..	.....	12	1.0284	..	.....

for deepest expiration and 2.34 for mid-respiration. As in the instance of the specific gravity-stature relations, the differences are probably caused by the inability of the younger boys to exhale completely.

The dispersion of specific gravity is greater in deepest expiration than in any other phase in the postnatal period, but not significantly so because the ratios of the differences between the standard deviations to their standard errors are always less than 2.

The level of specific gravity drops with onset of respiration from 1.052 to 1.016, or 0.036 units, then increases from 1.016 at birth to 1.041 at 24 years, a total of 0.025 units. The variability as estimated by a standard deviation of 0.013 is so high that an infant may have a specific gravity within the range of plus and minus one standard deviation of the regression line in the adult period, and vice versa. Deepest inspiration lowers the level at the age of 14 years to 0.986, which is 0.045 units lower than the value 1.031 calculated for quiet respiration (Equation 10). Deepest expiration increases it only 0.020 units to 1.051, and mid-respiration lowers it 0.013 units to 1.018.

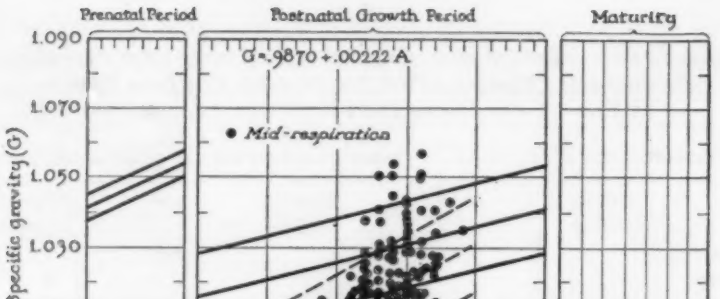

FIG. 6. GRAPH ILLUSTRATING THE EFFECT OF MID-RESPIRATION ON THE RELATION OF SPECIFIC GRAVITY TO AGE DURING QUIET RESPIRATION

The solid lines are the regression line and the plus one and minus one standard deviation lines of before respiration and during quiet respiration from Fig. 4. The three parallel broken lines represent the regression line and the plus one and minus one standard deviation lines for mid-respiration (Equation 14).

THE EFFECT OF OBESITY ON SPECIFIC GRAVITY

The data in the literature are inadequate for a statistical estimate of the amount that obesity would decrease specific gravity after adult stature is reached. However, since the specific gravity of human fat has been determined, the amount that obesity might decrease the specific gravity of an average man may be roughly approximated by increasing his weight in fat alone by a series of regular percentage increments. The values of specific gravity for human fat recorded in the literature are 0.9243 (Krause and Fischer, 1866) and 0.932 (C. Krause, 1844,[9] and Valentin, 1851), and for panniculus adiposus 0.971 (Vierordt, '06), so that 1 kg. of fat would have a volume of either 1.082 or 1.073 liters and 1 kg. of panniculus adiposus would have a volume of 1.030 liters.

[9] Quoted by Krause and Fischer, 1866. I have been unable to obtain the original reference.

For a man[10] measuring 165 cm. in height, the calculated specific gravity for quiet respiration is 1.0372 (Equation 3). When his weight is 60 kg., his volume (weight divided by specific gravity) becomes 57.848 liters. If his weight is increased 10, 20, 30, 40, 50 and 100 per cent in fat of the lower density and greater bulk reported by Krause and Fischer, his volume would be increased 11, 22, 34, 45, 56 and 112 per cent respectively, causing a decrease in specific gravity from 1.037 to 1.026, 1.017, 1.009, 1.002, 0.997 and 0.978, or 1.1, 2.0, 2.7, 3.4, 3.9 and 5.8 per cent respectively. If, on the other hand, his weight is increased the same amounts in panniculus adiposus with its higher specific gravity, his volume would be increased only 11, 21, 32, 43, 53 and 107 per cent respectively, causing a decrease in specific gravity from 1.037 to 1.031, 1.026, 1.021, 1.017, 1.014 and 1.003, or 0.6, 1.1, 1.6, 1.9, 2.2 and 3.3 per cent respectively. In short, when the weight of this hypothetical average man has increased 40 to 50 per cent in fat of low density, he could float while breathing quietly; but if his weight were increased in both fat and its supporting tissue, he could not float without some regulation of his respiration, even after his weight had been increased 100 per cent. The actual reduction is probably somewhere between the two sets of estimates, because in obesity other components of the body probably increase, especially water, even though the major increase is in fat.

SUMMARY

A statistical analysis of individual records culled from the literature demonstrates, within the limits of these data, that:

1. Specific gravity in all respiratory phases increases rectilinearly with both stature and age.

2. The increment of specific gravity with each centimeter increase of stature is not significantly different in the prenatal and postnatal periods.

3. The increment, 0.0002, of specific gravity during quiet respiration with each centimeter increase of stature is not essentially modified by changes in respiration, except as inability of the younger boys to exhale changes the slope of the regression lines for deepest expiration and mid-respiration.

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[10] I assumed an average man had the same height and weight as the average height and weight of Mies's volumetric data.

4. The rate of increase of specific gravity with age is much higher in the fetal period than in the postnatal.

5. The rate, 0.001, of increase in specific gravity with age in the postnatal period is not significantly modified by changes in respiration, except as the inability of the younger boys to exhale changes the slope of the regression lines for deepest expiration and mid-respiration.

6. Onset of respiration lowers the specific gravity from an average of 1.052 to 1.015 during quiet respiration.

7. Specific gravity in quiet respiration increases from an average of 1.015 at birth to 1.041 at maturity.

8. The variability of specific gravity at all ages is so great that in spite of the increase with age about one-sixth of normal infants would be expected to have specific gravities within the same zone as the central two-thirds of adult values; and, conversely, one-sixth of normal adults would have specific gravities within the central two-thirds of infant values.

9. Deepest inspiration in adolescence lowers the specific gravity on the average 0.048 units from the quiet respiration level to 0.986, while deepest expiration raises it only 0.017 units to 1.051. As a result the mid-respiration level is approximately 0.016 units below the quiet respiration level of specific gravity.

10. The usual range in specific gravity from deepest inspiration to deepest expiration is approximately 0.065 units, or 6.4 per cent.

11. In a hypothetical case, doubling the average adult weight in fat alone lowers the specific gravity during quiet respiration to 0.978 or 6 per cent, doubling the weight in panniculus adiposus lowers it only to 1.003 or 3 per cent.

12. These findings substantiate, in more concise terms, both the scientific and lay impressions that during quiet respiration the specific gravity of the human body is slightly greater than that of water, that it is closer to that of water in children than in adults, that deepest inspiration lowers the specific gravity below that of water in most subjects but not in all, and that obesity tends to decrease specific gravity.

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PIERRE-FRANÇOIS VERHULST, THE DISCOVERER OF THE LOGISTIC CURVE[1]

BY JOHN R. MINER

Since Malthus' *Essay on the Principle of Population* originated as a criticism of the English poor laws and of other attempts to ameliorate the condition of the poor, it is natural that much of the literature inspired by it was polemic rather than scientific in its point of view. However, in spite of its controversial character, the *Essay* contains the elements of a mathematical analysis of the growth of a population. If the means of subsistence could be increased without limit a population would grow at a constant rate of increase. If a generation of 1,000,000 persons brought 2,000,000 children to maturity, these 2,000,000 would in turn bring 4,000,000 children to maturity, and so on in geometrical progression. But the means of subsistence cannot be increased without limit. The area of the globe is fixed, and this sets a limit to the amount of crops that the farmers can raise. When the population is sparse only the most fertile lands are cultivated, but as it increases poorer and poorer lands, yielding less and less produce, are brought under cultivation. There are thus checks to the growth of a population in geometrical ratio. Malthus has been justly criticised for his assumption that the means of subsistence increase in arithmetic ratio. If this were true population would still increase without limit, although at a constantly diminishing rate. But it is plain, for the reasons stated above, that there must be some upper limit to population growth.

Other writers sought more satisfactory hypotheses of the numerical effect of the checks to population growth. Thus Quetelet,[2] the cele-

[1] From the Department of Biology, School of Hygiene and Public Health, Johns Hopkins University. I wish to thank Dr. Raymond Pearl, Dr. William M. Gafafer, Miss Hermine Grimm, and my wife for their suggestions.

[2] Quetelet, A. Sur l'homme et le développement de ses facultés, ou Essai de physique sociale. *Paris* (Bachelier), 1835; Lottin, J. Quetelet, Statisticien et Sociologue. *Louvain and Paris,* 1912; Hankins, F. H. Adolph Quetelet as Statistician. *Columbia University Studies in History, Economics and Public Law,* Vol. 31, No. 4, pp. 1-134, 1908.

brated Belgian statistician, assumed, by analogy with the resistance of a medium to the passage of a projectile, that the resistance to the growth of a population increases in proportion to the square of the velocity with which the population tends to increase. In 1838 Verhulst, a former pupil of Quetelet, suggested that the checks on the growth of a population increase in proportion to the population itself. In this way he obtained the familiar S-shaped curve, bounded by upper and lower asymptotes, which he christened the logistic curve. But census taking was still in its childhood, and the data were too few to demonstrate whether populations actually grew according to his hypothesis. Moreover, as a result of the Industrial Revolution, the checks which had threatened to curb the growth of population seemed to be removed, and interest in the population problem gradually waned. It thus happened that Verhulst's work was generally forgotten until after the independent rediscovery of the logistic curve by Pearl and Reed in 1920.[3]

Even before his work on population, Verhulst's health had begun to fail, and in 1849 he died. His *éloge*, by his former teacher, Quetelet, was published in the *Annuaire de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique* for 1850 (pp. 97-124). It is of interest, not only as showing what manner of man Verhulst was, but as throwing various sidelights on Quetelet's own character.

NOTICE
ON
PIERRE-FRANÇOIS VERHULST[4]
MEMBER OF THE ACADÉMIE ROYALE
Born at Brussels, October 28, 1804;
died February 15, 1849.

"The *éloge* of a man of letters should be the story of his works," says d'Alembert; "but," he adds, "it might also be useful to make known what he was, and to

[3] Pearl, R., and Reed, L. J. On the rate of growth of the population of the United States since 1790 and its mathematical representation, *Proc. Nat. Acad. Sci.*, Vol. 6, pp. 275-288, 1920.

So far as the author knows the only reference to the work of Verhulst in modern times prior to the paper of Pearl and Reed is that of L. G. Du Pasquier, Esquisse d'une nouvelle théorie de la population, *Vierteljahrschr. des Naturforsch. Ges. Zürich*, Vol. 63, pp. 236-249, 1918.

[4] This notice was read at the public meeting of the class of sciences of the Academy, December 16, 1849. The portrait which we give here was executed under the direction of M. Calamatta, from a drawing forming part of a collection of portraits belonging to the author of this *Notice*.

FIG. 1. PORTRAIT OF PIERRE-FRANÇOIS VERHULST
(1804-1849)

portray the man at the same time as the writer."[8] And in fact, to recall merely the works by which he has been able to serve science is to show him in an incomplete manner, to deprive him of his individuality, and to satisfy only imperfectly the curiosity of the reader.

In general, what interests us in a biography is to feel ourselves nearer to its subject; to be in some manner initiated into the secret of his thought; and, if he has distinguished himself by superior ability, to recognize, through the details of his private life, that he belonged to our kind, and that with some exertion we might perhaps have been able to raise ourselves to his height.

These details, moreover, are not without interest for the general history of the sciences and of letters. If one wishes to judge of the improvement which a writer has brought about, one must necessarily take account of the circumstances in which he found himself and of the obstacles which he had to overcome. It is above all the function of those who have lived in intimacy with him to collect impartially the data for appraising him which are almost always lacking when the moment

[8] Réflexions sur les éloges, Vol. 2, p. 151, of the Œuvres de d'Alembert, *Paris*, Belin, 1821.

to make use of them arrives. As a result of this conviction and in default of other merit, I have striven, in the different notices which I have had the honor to present to the Academy on those of our confreres whom death has struck, to be veracious before all, not, however, to the point of permitting myself to enter into all the details of their private life, especially in the presence of graves sometimes scarcely closed. "The purpose of literary *éloges*," again says d'Alembert, "is to render letters worthy of respect and not to discredit them."[6]

I hasten to say, the savant of whom I am to speak to you today has nothing to fear from reticence. His life was pure and limpid; one can examine it in all its parts without finding the least blemish. I myself have been able to follow its different phases. He was successively my pupil and my collaborator; my colleague at the *École militaire* and my confrere at the Academy; I am honored in having been his friend, from the moment when I first knew him until death separated us; I should therefore be able to count on your indulgence for the details in which I shall allow myself to be involved. These details moreover will find their justification in the especial evidences of esteem which you have given him, and in the very titles of director of the class of sciences and of president of the Academy, which honored his last days.

Pierre-François Verhulst was born at Brussels October 28, 1804. He belonged to a reputable family which left nothing undone to facilitate his studies. Entered early at the *Athénée* of his natal city, he applied himself with success to the study of the classics, and, two years in succession, he carried off prizes in Latin poetry. His inclinations impelled him, however, in preference towards the exact sciences; he devoted himself to them with ardor, even to the point of neglecting his rhetoric course; and in the month of August, 1822, he shared the first prizes in mathematics with MM. Plateau and Nerenburger whom he was destined to meet again later as confreres in the class of sciences of our Academy.

Since the time of the Empire, the *Athénée* or rather the *Lycée* of Brussels had given to the *École polytechnique* a series of distinguished pupils; the taste for the sciences had been maintained there; and by a concurrence of favorable circumstances it was at the epoch of which we speak in its most complete development. That establishment numbered in fact among its pupils a large number of men who have since distinguished themselves in higher education, the magistracy and the army.[7] However, never was the instruction reduced to simpler proportions; Is it perhaps to that very simplicity that the fecundity of the results which were there obtained was due? By not extending unduly the ground to be cleared, it is possible to reach greater depths.

Verhulst entered the University of Ghent in the month of September 1822, without even having finished his literary studies, so great was his desire to push

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[6] *Ibid.* To be more certain of staying within the truth, I have often borrowed, but within proper bounds, from the intimate correspondence of the authors whose lives I had to recount, the particulars which could best characterize them.

[7] Among others the university professors, MM. Plateau, Kickx, Verhulst, Morren, Nypels, DeCuyper, Guiette, Van Esschen, Kindt, Van Ginderachter, Uytterhoeven, etc.

forward in the exact sciences. This lack of formality caused him some difficulty in obtaining his matriculation as pupil in the faculty of sciences.

Among the savants to whom he had been directed, he was particularly drawn to Dandelin, for whom he conceived a genuine admiration; and in fact it could not well have been otherwise. This is how, in a letter which he wrote at this period, he gives an account of his first relations with that savant, whose tomb was one day to be placed so near to his: "I shall not sing the praises of M. Dandelin to you; you are well enough acquainted with him to know how to appreciate perfectly his obliging character and his vast knowledge of the sciences. I can assure you that the conversations which I have had with him have given me the highest idea of him. When I state to him whatever difficulty puzzles me, he gives me at once all the explanations desirable, stated with a facility and a clarity, which more than once have excited my admiration. He treats his most interesting discoveries like trifles."

The studies of Verhulst at the University of Ghent were, as at the *Athénée royal* of Brussels, crowned with full success. A single year saw him bear away two academic palms; in the month of February 1824, he was crowned by the faculty of sciences of the University of Leyden for a memoir on the theory of maxima and minima; and in the month of October of the same year he received the gold medal of the faculty of sciences of Ghent for a work on the calculus of variations. It would be unjust, I take it, to demand of the young authors of such works anything more than method and elegance in exposition; mathematical invention should not be a necessary condition of such a competition.

The prize on the question of maxima and minima was shared with M. Verdam, a student at the University of Leyden. One may see in the *Correspondance mathématique et physique*,[8] an analysis of the works of the two competitors, made by M. Garnier, our former confrere. The author of this analysis has not turned the scale in favor of his pupil; he lets it be inferred on the contrary that his judgment would have been unfavorable, if he had been called to pronounce it.

As to the second memoir on the calculus of variations, M. Garnier limits himself to promising an analysis of it[9] which he never published. There did not exist between the professor and the pupil that sympathy so favorable to studies and so fitted to assure success in them.

We have already had occasion, in the notice devoted to M. Garnier, to remark that troubles, experienced in his professorial career, had rendered him mistrustful in his relations with his pupils. On the other hand, the young Verhulst had not perhaps preserved at the University of Ghent all the modesty that he had brought there, and he may have offended, without intending it, an old man distrustful by nature.

Two academic prizes borne off in succession and the ovations which are their consequence; would more be needed to excite the vanity of a young man, devoid moreover of experience and of advisers? In the midst of his flights of vanity Verhulst still preserved his original simplicity; everything that he learned he believed to be new to others; he questioned them, pressed them on the field which

[8] Vol. I, pp. 23 *et seq.*

[9] *Ibid.*, p. 284.

he believed he alone had conquered; and, like Gil Blas, he began with ardor arguments of which it was sometimes very difficult to foresee the conclusion. Discussion always had for him a strong attraction. This taste for scientific disputes became much tempered, however, on his quitting the benches of the school where he had made his first progress.

The same inconstancy which had brought him to the University of Ghent without having finished his literary studies led him to take his academic degree sooner than his interest seemed to require. He sustained his dissertation for the degree of Doctor of Science, August 3, 1825, after less than three years of university study. This dissertation, which treated of the algebraic and linear solution of binomial equations, was dedicated to Commander de Nieuport, that venerable old man who has filled by himself almost a whole epoch of transition in our history of science.

Although we are not far removed from the time when our Universities were organized, nevertheless every day the remembrance of it grows fainter. The faculties of science in the beginning were each composed of only three or four professors. Instruction was reduced to its simplest forms and was given so to speak *en famille*. The examinations had scarcely any other function than to fulfill an obligatory formality; I do not think that any candidate for the doctorate of science had ever been rejected. In fact no student would have dared present himself for examination without being well prepared for it and without having previously obtained the consent of his professors. If he distinguished himself in one branch, he was sure in advance that he would find indulgent judges in those which he had had to neglect. This vast field open to the development of specialities has contributed remarkably to the production of the excellent results which the former faculties of science gave.

The revolution of 1830, in proclaiming liberty of instruction, had necessarily to introduce a reform in examinations and in consequence to modify the relations between the professors and the students. Therefore one sees the latter less occupied with science than with the desire to satisfy examiners most of whom are completely unknown to them. Being required to give their attention equally to a considerable number of branches of human knowledge, they find it in general impossible to get to the bottom of any one of them.[20] As there do not even exist syllabuses which specify the limits within which they should confine themselves, their admission always remains problematical. Would it be an exaggeration to say that the

[20] Physics figures as many as three times among the sciences forming the subject of instruction, under the names of experimental physics, mathematical physics and industrial physics. One could add to them also medical physics, agricultural physics, the physics of the globe, etc. There would be at this rate as many kinds of physics as one could make combinations between physics and the other sciences. Would it not be preferable to rest content simply with teaching physics? As to the names of mathematical physics, mathematical astronomy, etc., which are employed often enough, one might as well say English physics, German physics, because the principles of physics were written in those languages. Mathematics also forms a language and for those who know it, it suffices for the study of physics and astronomy.

Doctors of Science, even the most distinguished, trained in the old universities would very probably have failed before modern examining boards? The present state of affairs may be advantageous for the government service, where it is much less a question of creating men distinguished in one or another specialty than of training employees with a knowledge of everything that their duties require. But here at least has been understood the necessity of programs in which nothing is left uncertain or committed to the discretion of the judges.

Too great a multiplicity of studies ends by producing satiety, and often the young man, after having laboriously won his degree, abandons science completely. Verhulst had by no means reached this sad extremity; he intended, on the contrary, to return to Brussels only to devote himself more exclusively to the part of mathematics for which he had the greatest fondness. At that time the theory of numbers attracted all his attention; he inserted various results of his researches into the *Correspondance mathématique et physique*, and promised to become one of the most assiduous collaborators in that periodical, in the editing of which at that time almost all the young Belgian mathematicians who have since made a name in science coöperated.

However a royal decree which appeared at that time and which regulated the payment of the funded debt by lot at intervals of 25 years [*par la voie du sort et de 25 en 25 ans*] caused our young geometer to descend from the region of abstractions into the field of political arithmetic. Another royal decree, which established a new lottery, led him to examine the chances which the institution offered and to value its financial as well as its moral aspect.

Since his earliest studies Verhulst had always had the most sincere attachment to me; he often consulted me on the direction to give to his work; I thought it my duty to advise him to remain in the path on which he had entered and for which he showed an especial aptitude. It might be useful, moreover, to have a few men who were qualified to make researches on questions of general interest connected with the mathematical sciences.

He began to study the theory of probabilities and to familiarize himself with the principles of political economy; there he found himself in a new field, but one still undeveloped and poorly limited; where he could give full scope to his taste for discussion; therefore this kind of studies became for him the object of a new passion.

Verhulst had spoken to me of publishing a complete edition of the works of Euler, that admirable model of mathematical elegance. I thought it my duty to urge him, before undertaking so difficult a task, to consult the most competent men in these matters; and I directed him to M. Poisson, who had no difficulty in dissuading him from his project.

He desired, however, to employ his leisure usefully and make a diversion from his other studies. I suggested to him the translation of the *Treatise on Light* by Sir John Herschel, which had appeared serially in the vast collection of the *Encyclopaedia Metropolitana* of London. It would be useful to make known on the continent that excellent work, access to which was so difficult for physicists. We were to collaborate in the translation; our parts changed later; Verhulst alone applied himself to that task, and I assumed the preparation of the supplement to the work of the illustrious English astronomer.

Meanwhile the Government had organized public classes at the Brussels Museum, where for several years I had been entrusted with the teaching of experimental physics. As mathematics was not included in this organization, I engaged three of my former pupils to fill this gap.

M. Verhulst had agreed to give the course in analysis, but he soon had to lay down the new task which he had assumed; his health had become considerably impaired.[11] He struggled for a long time against the disease, which made rapid progress; but yielding at last to the advice of his friends, he formed the resolution of repairing to a more favorable climate, and departed for Italy at the beginning of 1830.

He had taken with him the books necessary for his studies; but scarcely had he arrived at Turin when he found it necessary to renounce his desire to carry them farther, to avoid incessant disputes with the customs authorities of the petty states which he must traverse. He visited successively Milan, Bologna, Florence, Pisa, Leghorn, and Rome, taking care in each place to put himself in communication with the most eminent men of science. I followed him closely in these different towns, but on arriving at Rome I was sorry to learn that we had passed each other on the road from Florence. We were near each other at the end of September; the revolution which had broken out in Belgium made a great sensation in Italy, where its results were considerably exaggerated. I found it necessary to quit Rome precipitately, without having seen Verhulst, who did not return until several days after my departure.

It was at that epoch and under the influence of the news which he received from France and from Belgium that there entered his mind one of those projects which can scarcely be entertained except by young men devoid of experience of men and affairs. He conceived the idea of bringing about a reform in the Papal States and of persuading the Holy Father to grant a constitution to his people. He did not rest content with the idea. Verhulst always went straight on to the consequences of a principle, with all the resolution which full conviction gives. He draughted the constitutional pact, and communicated it to some of the cardinals by whom he had been well received. What will perhaps scarcely be believed is that this project was taken into consideration and referred confidentially to several foreign ministers for their opinion. But the affair passed from the hands of the diplomats to that of the police, and our compatriot abruptly received the order to leave Rome.

Friendly warnings had already made him fear that the police might come to attack him in his dwelling. Verhulst resolved to barricade himself; and, if necessary, to sustain a siege; he had made preparations for everything, even for a hiding place, in case his first line of defense were carried. He had wished to join with him in his plans of resistance one of our confreres of the class of letters, who at that time shared his apartment but not his bellicose ardor. These details I had from the mouth of Verhulst himself; and if they are mentioned here, it is because they had some notoriety in the newspapers and the memoirs of the period.[12]

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[11] This state of ill health seemed particularly due to excess of work and to an unusual development of stature; his height was 1.89 meters or about 6 feet.

[12] Especially in the *Mémoires* of Queen Hortense, who had received our young geometer kindly.

Queen Hortense's [18] account of this incident is much livelier than Quetelet's somewhat turgid prose.

A young Belgian savant, M. Verhulst, had come to Rome for his health. He came very often to my house in the evening; we had frequent discussions together. He asked to speak to me one morning, and brought a plan for a constitution for the Papal States, which he wished to submit to my criticism before giving it to the cardinal-vicar to submit to the Pope. I could not help laughing at the singularity of my position. I, to revise a constitution, and for the Pope! That seemed to me like a joke.

But my young Belgian did not laugh. "I was talking all yesterday evening," he said to me, "with several cardinals; their terror is great. I told them of the only way to save the Church and the State. They agreed with all my observations, and one of them wishes to submit them today to the Pope himself. Here is the constitution of which I have sketched the basis."

"Alas!" I said to him, "if the Pope were the man to make suitable concessions, he would be tomorrow the leader of all Italy. Perhaps he would dictate laws to Europe, and restore to religion, allied with liberty, the splendor which it formerly possessed. But do you really believe that these good clerics will understand a word of what you tell them? Every change will seem to them a sacrilege. Nevertheless let us read your project; but, I tell you beforehand, it is labor lost."

We discussed one article after another of the new constitution, which gave to all the Romans the opportunity to rise to office, and which yet could satisfy, to a certain extent, both the nobility and the clergy. I made him change various provisions which, seeming to encroach on the spiritual power, were likely to offend the Sacred College. He approved all my observations, and departed enchanted with his work.

I have always remarked that youth, animated with the wish to be useful, judges according to its own ardor, and never doubts of success. I too have shared these illusions, but experience has disenchanted me. After having seen the greatest genius often so little understood, even by people of intelligence, could I believe that good clerics, completely ignorant of the new ideas which are ready to turn the world upside-down, accustomed to omnipotence received from a God, would be willing to change anything? One would have had to make them over. I did not deceive myself. Next day there was a large soirée at King Jerome's; he said to me: "I have just learned that that young Belgian who comes to visit you is making the papal government uneasy; they believe him to be a revolutionary and are beginning to be alarmed about him. There is even talk of banishing him from Rome." That is how he was rewarded for his good advice. (Vol. 3, pp. 210-212.)

We return now, after this digression, to Quetelet's account:

After this episode our young compatriot returned to Belgium; suffice it to say that he did not hold himself aloof from the events that were then taking place.

[18] La Reine Hortense en Italie en France et en Angleterre pendant l'Année 1831, republished in Mémoires de la Reine Hortense publiés par le Prince Napoléon, 3 vol., *Paris* (Plon) [1927].

He soon acquainted himself with the true state of things and displayed an activity which seemed to indicate a complete restoration of his health. When, towards the middle of 1831, the Dutch army invaded our territory, Verhulst, in spite of all the remonstrances of his friends, was fully resolved to join the army. On the ninth of August, about 9 o'clock in the morning, I received from him the following note: "I leave today at 10 o'clock for headquarters, commanded by the ministry to accompany the army in order to keep the Government informed of the movements of our troops."

Once launched into political affairs, Verhulst abandoned his mathematical studies almost completely and became a candidate for membership in the Chamber of Representatives. However, his candidacy was not as successful as he had anticipated, and I believe that this was a fortunate thing for him.

Should savants, and especially artists, seek to appear in the parliamentary arena? One may doubt it when one considers that few have distinguished themselves there, and that many on the contrary have lost their reputation. It will be maintained perhaps that the commonwealth has gained thereby; the assertion is still more problematical; in most cases, the State loses men eminent in their specialty, and it is often difficult to replace them, except in the place which they have believed it their duty to seek. The true source of their talent, imagination, in place of exercising itself and developing itself in deliberative assemblies, ends on the contrary by becoming deadened and extinguished in the presence of interests, almost always material, on which the discussions bear.

In the midst of his political preoccupations Verhulst reread our national history and sought there eagerly for epochs which might offer some analogy with that in which the country then found itself. This study led him to write the *Précis historique des troubles de Bruxelles, en 1718* with hitherto unpublished details of the trial and execution of Agneessens, whom the people of Brussels still consider one of the martyrs to their liberty.[14] This pamphlet is written in an interesting style and proves that the author would not have found himself out of place in the field of history if he had thought fit to tarry there.

When in 1832 I applied myself to collecting the necessary data to calculate the first general tables of mortality for Belgium in which the distinction of sexes is made, Verhulst consented to aid me in this laborious task. It was, moreover, at my request that he had calculated in 1827 a mortality table for the city of Amsterdam, making use of data collected in the *Annuaires* of Lobatto.[15]

This kind of researches drew his attention to a work relating to *Populations spécifiques* published by Baron de Prony in the *Annuaire du bureau des longitudes de France*. The paper which he wrote on this subject was inserted in the same *Annuaire* for 1833. The illustrious French mathematician courteously recognized the worth of the observations of the young Belgian mathematician, and addressed to him an interesting letter on that subject in which he corrected several of his former calculations.[16]

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[14] Paper, 18mo, 72 pp. *Brussels* (Th. Lejeune), 1832.

[15] See Vol. 3, p. 105, *Correspondance mathématique et physique*.

[16] *Ibid.*, Vol. 8, p. 227 *et seq.*

In 1834 Verhulst had formed a connection with the *École militaire;* he had begun by performing gratuitously the functions of tutor in analysis. On being later appointed professor, he devoted himself entirely to the fulfillment of his important duties. What more worthy eulogy could one make as to his professional career than that which the honorable commandant of the *École militaire,* who could appreciate all his eminent qualities, pronounced over his tomb? "In his office of professor," said General Chapelié, "in his relations with his colleagues and with his pupils, Verhulst showed constantly both the wish to be useful and the sentiments of justice and equity with which he was permeated. He drew up the syllabus of the courses with which he was entrusted. Each year this work was improved upon. He applied himself to it earnestly, and strove, while keeping his résumés up to the high standards of science, to clear up the difficulties which the study of mathematics offers."

Feeling the need of concentrating his affections, Verhulst had allied himself with a family distinguished in the fine arts and the sciences.[17] He had married in 1837 Mlle. Debiefve; and from that union was born a daughter who later contributed to give him, in his private life, a tranquil happiness for which the state of his health scarcely permitted him to hope.

Our most important works often spring from slight causes. Verhulst had bought at a public sale a fine copy of the works of Legendre. The pleasure which this acquisition gave him inspired in him the desire to study the *Traité des fonctions elliptiques.* Insensibly the sphere of researches extended itself, and he conceived the idea of summing up in an elementary treatise the principal analytical results obtained by Legendre, Abel and Jacobi. He did not shrink before the difficulties of such an enterprise; he began to read, pen in hand, not only the different memoirs of these illustrious mathematicians but further all the literature relating to this subject and ended by publishing in 1841 his principal work, the *Traité élémentaire des fonctions elliptiques,* intended to follow the elementary treatises on the integral calculus.[18]

The publication of this book was a true service rendered to science; more than common talent was requisite to bring into the domain of teaching a series of works in higher mathematics which were dispersed in different collections and written in different languages. Perhaps the author erred in substituting various new notations for those generally received; he did it, however, only with the greatest caution and with protestations of his *repugnance for innovations.*

The publication of the *Traité des fonctions elliptiques* opened to him the doors of our Academy; Verhulst was elected correspondent of the section of sciences, May 7, 1841; in the general meeting of the month of December of the same year

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[17] He had for brothers-in-law Dr. Debiefve and M. Ed. Debiefve, one of our principal painters. His brother, on the maternal side, M. Wynants, is captain of engineers in the Belgian army.

[18] M. Garnier has given an analysis of this work in the *Bulletins* of the Academy for 1840, part 1, p. 322 *et seq.*

M. Verhulst, with characteristic honesty, made it known that several tables in his work had been calculated by M. Loxhay, his former pupil and his friend, who gave him the most touching care during his last illness.

he was elected member, taking the place of M. Garnier, his former professor at the University of Ghent. These two distinctions, given at times so near each other by the foremost learned body of his country, were not the sole recompense of his labors. The King conferred on him the cross of chevalier of his order, and the Government reimbursed him for the cost of publication of his book, of which the number of readers must be quite limited since the subject requires a thorough knowledge of mathematics.

As early as the month of September of the same year Verhulst had been compelled to return to Italy in order to find a climate more favorable for his health. His absence was prolonged until spring; and on his return one might have believed, as before, that he had completely recovered. However, his intellectual faculties had lost their vigor; he renounced almost entirely the mathematical studies which required too continued labor. Nevertheless, he published in 1847 a little pamphlet entitled *Leçon d'arithmetique dédiée aux candidats aux écoles spéciales*;[19] in it he sought to present various simplifications in the ordinary operations of multiplication and division and in the methods of determining the degree of approximation which one has reached in extracting the cube root.

His attention was more particularly turned towards the political sciences and towards the theory of population. The following was his topic. It is generally agreed that the tendency of a population to increase follows a geometrical progression; this is Malthus' law. However, numerous obstacles are opposed to the expression of this mathematical law in practice. The celebrated English economist, who had carefully enumerated and examined these obstacles, had kept silence on their mode of action. In my *Essai de physique sociale* I had thought myself justified in asserting that the resistance or the sum of the obstacles opposed to the unlimited growth of population, increases in proportion *to the square of the velocity with which the population tends to increase.* An analogous proposition had been advanced by Fourier, the illustrious author of the *Théorie de la chaleur,* in his introduction to the first volume of the *Recherches statistiques sur Paris.*[20] I requested M. Verhulst to submit this principle to a thorough examination and to apply it to the best data known on population. Our confrere was willing to accede to my request, and published the results of his researches in volume X of the *Correspondance mathématique et physique.* He was led to the conclusion that the observed data were still too few to verify the principle stated in such fashion as to leave no doubt of its exactitude; or, in other words, that theory had outstripped observation and that it would be prudent to halt. Nevertheless he did not abide by these discreet conclusions; and in the next year (1844),[21] he presented to us a memoir entitled *Recherches mathématiques sur la loi d'accroissement de la population*;[22] one finds in this work, which is moreover remarkable in other respects, various conclusions which may be considered at the very least as bold. But then

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[19] 12mo, *Brussels,* 1847.

[20] Vol. 1, p. 277, *Paris* (Bachelier), 1835.

[21] [Verhulst's first note was published in 1838. J. R. M.]

[22] Vol. 18, *Mémoires de l'Académie royale de Bruxelles.*

the author resumed his work with that patience and that honesty which characterized him; and in 1846 he presented a second memoir on the same subject.[33]

In investigating in his turn the mode of action of the obstacles to the growth of population, our confrere believed that he could establish in principle that *they increase in proportion to the ratio of the superabundant population to the total population.* On the basis of this hypothesis he tried to find the limits within which the Belgian population should always be confined, and he fixed the upper limit at 9,400,000 inhabitants. In his earlier memoir he had fixed the same limit at 6,600,000 inhabitants, on the basis, this time, of the principle that the obstacles increase *exactly in the same proportion* as the superabundant population.

It will be understood that when one enters the field of hypotheses he can give free rein to his imagination; especially when observations are lacking to put them to proof. If anything can justify them, it is the law of analogy; but there does not exist, to our knowledge, any principle in nature analogous to that postulated by our learned confrere.

He showed himself, on the other hand, unfavorable to the application of the theory of probabilities to moral phenomena, and particularly to the deductions *a posteriori* which are drawn from the observation of facts. He evinced, in this respect, a caution and a timidity which one might regard as extreme; he considered numerical methods applicable only when one perceives a direct relation between cause and effect. His conviction appeared shaken, however, when one reminded him of tables of mortality and of the various applications which had been made of them, even in his own writings.

Towards the end of his life, he returned again to his favorite theme and confided to me that he was considering for our public meeting, an address in which he would undertake to combat my ideas on the theory of probabilities as applied to moral statistics; he feared that his health would not permit him to read it; I offered to read it for him, saying that the refutation of it would be so much the more piquant. The idea made him smile, but he had neither time nor strength to carry out this project.

Less exclusive than most political writers, he accorded an equal importance to statistics and to social economy. He did not think, as is so often done in our time, that it is necessary to sacrifice one of these two sciences to the other. Have we not seen of late France suppressing its course in political economy in the *Collége de France* and substituting for it different courses in statistics, whereas among us, as if by way of reprisal, political economy gained the upper hand and the name of statistics disappeared from the programs of our Universities?

Belgium, however, by a glorious initiative, put its statistical work in order and gave the example of the greatest census that has ever been carried out among any people.[34] It is when a science is in its infancy that it is especially important to follow, as a faithful and impartial historian, the different phases which its first developments present and to point out the causes which can accelerate or retard its progress.

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[33] Vol. 20, *Mémoires de l'Académie royale*, 1847. Read at the meeting of May 15, 1846.

[34] The triple census of population, of agriculture and of industry.

The nature of the studies of our confrere, the excellent qualities of his heart and his inflexible principles of rectitude procured him numerous tokens of esteem and of confidence. I shall cite in particular the laborious functions of *maître des pauvres* which he fulfilled as long as the state of his health permitted.

During the last days of his life the Government had appointed him successively to the commission for the amelioration of the condition of the poor in Flanders and to that for general insurance by the State. The class of sciences, for its part, had named him its director for 1848 and the King had conferred on him, for the same year, the title of president of the Academy.

You know how he strove to justify this distinction by his upright and conciliatory spirit, by his agreeable and polite manners. He avoided with the greatest care everything that might cause discord in the class. He never made wounding remarks; he showed himself more modest the higher his position became.

Free himself from any personal susceptibility, he religiously respected those of others. If he argued, it was from the desire to instruct himself and not from the spirit of contradiction or to force his opinions on others. What distinguished him above all was an unalterable evenness of temper.

It would have been difficult to be a more rigorous observer of his duties. "To judge of the courage of the man of whom we deplore the loss, one must have seen him, as we have," said the honorable General Chapelié beside his tomb, "one must have seen him obliged to rest at each step to reach his class-room and arrive breathless, gasping, after having taken nearly an hour to traverse the short distance which separated his home from the school."

I have already recalled that on his death bed he did not consider that his sufferings could serve him as an excuse to neglect what he regarded as his duties as president of the Academy. It is in this very place, in this public meeting, that he had wished to make himself heard one last time, as in like circumstances Colonel Dandelin desired to devote his last breath to thank you publicly for having named him director of the class of sciences.*

There was another duty to the fulfillment of which our confrere attached no less importance. Our customs reserve to the president the honor of expressing to the King our felicitations on each New Year's Day. Verhulst had prepared the address which he intended to make; he had, so to speak, calculated the physical strength necessary for him to mount the grand staircase of the palace; but here again the gravity of his illness frustrated all his preparations. He confided to me the chagrin which this caused him. I promised him that his desires would not be completely baffled and that the King would hear the words which he had intended to address to him. I hastened to speak of it to M. Fetis, his successor in the presidency; and our learned confrere, with all the modesty and the benevolence which commonly accompany superior ability, was willing to accept this mission, perhaps unusual but dictated by a pious sentiment.

From that time the existence of Verhulst was only a long agony which he endured with a resignation and a courage of which it would be difficult to give an idea. Accustomed to struggle against the disease, he alone did not foresee its

* By a singular coincidence, both died on February 15, one in 1847, the other in 1849.

approaching end, although he studied it like a problem and observed himself die, if I may thus express myself. His extreme good-nature did not give way for an instant; even on the day before his death, when his voice did not permit him to express his thoughts, he stretched out his hand to me affectionately, wishing to convey all his gratitude to his confreres for the sentiments of friendship which I had just expressed to him in their name. He died calmly, after having received the consolations of religion, and in the midst of the most touching attentions of his family, on February 15, 1849, about seven o'clock in the evening.

Approche-t-il du but, quitte-t-il ce séjour;
Rien ne trouble sa fin; c'est le soir d'un beau jour.[36]

A. QUETELET

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2. Petri Francisci Verhulst commentatio ad quaestionem mathematicam a nobilissimo disciplinarum math. et physicarum ordine Academiae gandavensis propositam an. MDCCCXXIII, quae praemium reportavit die IV octobris MDCCCXXIV. Paper, 4to, *Ghent,* 1825.

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[36] His funeral drew a great concourse of people; several addresses were delivered over his grave: in the name of the Academy, by the permanent secretary; for the *École militaire,* by General Chapelié, commandant of that establishment, and by M. Ferrier, cadet ensign, in the name of his comrades, who were all present at this sad ceremony.

MÉMOIRES DE L'ACADÉMIE

8. Recherches mathématiques sur la loi d'accroissement de la population. Vol. 18, pp. 1-38, 1845.

9. Deuxième mémoire sur la loi d'accroissement de la population. Vol. 20, pp. 1-32, 1847.

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10. Sur la réduction des fonctions elliptiques de la troisième espèce à paramètre circulaire, à des fonctions de deux arguments. Vol. 6, part 1, p. 2, 1839.

11. Calcul approximatif des transcendantes elliptiques. Vol. 6, part 2, p. 424, 1839.

12. Sur une nouvelle manière de trouver à priori la différentielle de $y = \log x$. Vol. 7, part 1, p. 53 *et seq.*, 1840.

13. Note sur l'équation approchée $F'(c) = \log \frac{4}{b}$. Vol. 10, part 2, p. 378, 1843.

Note.—The *Bulletins* contain, besides, various reports made by Verhulst.

CORRESPONDANCE MATHÉMATIQUE ET PHYSIQUE

14. Solution de la question: Si l'on désigne par $m + n\sqrt{-1}$ une des valeurs de la racine n^{me} d'une quantité quelconque réelle positive ou négative $\pm z$ on aura identiquement

$$\sqrt{m^2+n^2}\,\sqrt[n]{\pm 1} = \sqrt[n]{\pm z},$$

les signes supérieurs ayant lieu en même temps dans les deux membres de l'équation, aussi bien que les signes inférieurs. Vol. 2, p. 80.

15. Solution de la question: On demande ce que devient, au bout de n années, un capital z à r pour 100, lorsqu'à la fin de la première année on retranche du capital augmenté des intérêts, une somme égale à c, ce qui donnera lieu à une différence que l'on placera également à r pour 100, en ajoutant les intérêts au capital, mais dont on retranchera $2c$; et ainsi de suite, en retranchant successivement $3c$, $4c$. . . . nc, à la fin de la 3^e, 4^e . . . n^e années. Vol. 2, p. 196. (This question was presented on the occasion of a royal decree which regulated the payment of the funded debt by lot at intervals of 25 years.)

16. Démonstration du théorème de Fermat: Soit p un nombre premier et a un nombre quelconque premier avec p, la puissance $a^{p-1}-1$ sera exactement divisible par p. Vol. 3, p. 5.

17. Démonstration du théorème de Wilson: si p désigne un nombre premier, le produit $1 \times 2 \times 3 \ldots p-1$, augmenté de l'unité, sera divisible par p. Vol. 3, p. 71.

18. Solution du problème: On donne dans un plan un angle et un point, et l'on demande de faire passer par le point une droite qui coupe les deux côtés de l'angle, de manière que l'aire interceptée soit de grandeur donnée. Vol. 3, p. 269.

19. Tableux des chances de la nouvelle loterie, établie par arrêté de Sa Majesté, en date du 13 novembre 1827. Vol. 4, p. 57.

20. Correction to preceding article. Vol. 4, p. 141.

21. Note sur un article d'analyse de M. de Montferrier. Vol. 5, p. 174.

22. Sur l'intégration de quelques équations différentielles, relatives au problème des oscillations du pendule simple dans un milieu résistant. Vol. 5, p. 329.

23. Note sur l'expression de l'aire d'un quadrilatère, donnée par M. Lefèvre, dans son TRAITÉ D'ARPENTAGE. Vol. 6, p. 120.

24. Note sur une remarque de M. Pagani, relative au mouvement rectiligne d'un point matèriel attiré par un centre fixe. Vol. 7, p. 183.

25. Notice sur la loi que la population suit dans son accroissement. Vol. 10, p. 113.

26. Sur la réduction des fonctions elliptiques de la troisième espèce à paramètre circulaire, à des fonctions de deux arguments. Vol. 11, p. 225.

SOMATIC HOMOGAMY IN MAN

BY RAYMOND ROYCE WILLOUGHBY

The publication in 1928 of the original data (3) from which Boas derived his famous conclusions as to the power of environment to modify heretofore supposedly constant somatic characters (2) made it possible to analyze with other objectives perhaps the largest body of careful measurements of related persons ever assembled. The passage of five years, however, has to the writer's knowledge seen the appearance of no such analysis, and an inquiry addressed to Dr. Boas has failed to elicit any information beyond that contained in his brief preface. Accordingly the author, taking care to avoid those topics (growth and heredity) indicated in the said preface as the province of future studies under Dr. Boas' direction, has found occasion to analyze these rich data with fair thoroughness with the aim of determining what light they throw upon the problem of assortative mating. The results of the analysis are presented herewith.

ABSOLUTE SIZE OF THE VARIABLES

On account of the mechanical inconveniences of reproducing full distributions, and since there is nothing anomalous about them, the means may be used to summarize the facts as to the size of the variables. In Table 1, the ages are recorded in years, the indices (WFI and CI) in hundredths, the head measurements in millimeters, and the stature in centimeters.

The following generalizations suggest themselves on the basis of Table 1:

(1) There are sex differences of considerable size in favor of the fathers in age and in all direct measurements; these are remarkably constant as between the national groups, being about 4 years in age, 10 centimeters in stature, 8 millimeters in head length, 6 millimeters in head width, and 7 millimeters in face width.

(2) The sex differences in the indices are very slight, but are consistently in favor of the fathers in the facial index and almost consis-

TABLE 1

Means

	AGE	ST [1]	LH [2]	WH [3]	WF [4]	CI [5]	WFI [6]	N
Sicilians—								
Fathers	43.3	165.6	192.7	150.0	139.5	78.0	93.9	336
Mothers	38.1	155.3	184.6	144.3	132.1	78.3	91.3	
Central Italians—								
Fathers	43.7	165.1	189.4	152.9	141.2	80.7	92.5	284
Mothers	38.9	154.5	181.7	146.6	133.4	81.8	91.0	
Hungarians-Slovaks—								
Fathers	39.2	167.1	187.4	157.7	143.4	84.3	91.0	91
Mothers	35.0	156.3	180.2	152.1	136.0	84.6	89.0	
Bohemians—								
Fathers	43.0	168.5	191.1	162.3	143.7	83.1	90.0	294
Mothers	39.9	157.7	181.1	153.5	135.9	85.6	87.0	
Poles—								
Fathers	40.2	166.9	190.6	156.4	143.2	82.5	91.6	64
Mothers	35.5	156.2	181.4	149.4	135.8	82.5	91.2	
Hebrews—								
Fathers	40.7	164.3	188.6	155.8	140.7	82.7	90.4	618
Mothers	37.1	154.6	180.9	150.6	133.6	83.3	88.8	
Scotch—								
Fathers	47.9	171.6	198.2	155.8	141.6	78.6	91.0	37
Mothers	44.4	161.5	189.3	148.6	134.2	78.5	90.2	

[1] Stature. [2] Head length. [3] Head width. [4] Face width. [5] Cephalic index, WH/LH. [6] Facial index, WF/WH.

tently in favor of the mothers in the cephalic index; as between the national groups they range from .4 to 3.0 (hundredths) for the former and —.1 to 2.5 in the latter.

(3) The order of stature among the groups is

Fathers	*Mothers*
Scotch	Scotch
Bohemians	Bohemians
Hungarians	Hungarians
Poles	Poles
Sicilians	Sicilians
Italians	Hebrews
Hebrews	Italians

That in head length is

Fathers	*Mothers*
Scotch	Scotch
Sicilians	Sicilians
Bohemians	Italians
Poles	Poles
Italians	Bohemians
Hebrews	Hebrews
Hungarians	Hungarians

That in head width is

Fathers	*Mothers*
Bohemians	Bohemians
Hungarians	Hungarians
Poles	Hebrews
Hebrews	Poles
Scotch	Scotch
Italians	Italians
Sicilians	Sicilians

That in face width is

Fathers	*Mothers*
Bohemians	Hungarians
Hungarians	Bohemians
Poles	Poles
Scotch	Scotch
Italians	Hebrews
Hebrews	Italians
Sicilians	Sicilians

That in cephalic index is

Fathers	*Mothers*
Hungarians	Bohemians
Bohemians	Hungarians
Hebrews	Hebrews
Poles	Poles
Italians	Italians
Scotch	Scotch
Sicilians	Sicilians

And that in facial index is

Fathers	*Mothers*
Sicilians	Sicilians
Italians	Poles
Poles	Italians
Hungarians	Scotch
Scotch	Hungarians
Hebrews	Hebrews
Bohemians	Bohemians

It is to be understood, of course, that many of the differences on which these ranks are based are so slight as to be insignificant, so that the rankings must be understood rather broadly. With this limitation, however, they conform rather well to the usual conceptions of the tall Scotchman, the short Italian, the broad-faced Slav, etc.

VARIABILITY OF THE VARIABLES

The standard deviation will first be presented in Table 2 for the various measures; in making sex comparisons, etc., this figure is often more significant than the coefficient of variation. As before, ages are in terms of years, stature in centimeters, head measurements in millimeters, and indices in hundredths.

A source of interest in the data of Table 2 is the sex difference in variability; this is without exception in favor of the fathers in age, predominantly in favor of the fathers in the head measurements (17 comparisons out of 21, with one equal), and slightly in favor of the fathers in stature (3 comparisons out of 7, with two equal) and in the indices (8 comparisons out of 14). This appears to be related to the

greater size of the male, and the relative variability may therefore be expected to show little sex difference; using only the head measurements of the four populations of significant size, we have the V's given in Table 3.

TABLE 2

Standard Deviations

	AGE	ST	LH	WH	WF	CI	WFI	N
Sicilians—								
Fathers	9.2	5.8	6.0	5.2	5.3	3.1	2.9	337
Mothers	8.8	5.8	6.0	5.1	4.8	3.4	3.0	
Italians—								
Fathers	9.4	5.5	6.8	5.7	5.5	4.0	3.2	284
Mothers	9.1	5.6	6.1	5.4	5.4	2.5	2.9	
Hungarians—								
Fathers	7.0	6.6	6.4	5.6	4.8	3.1	3.0	91
Mothers	6.8	5.9	6.0	5.2	5.6	3.3	2.9	
Bohemians—								
Fathers	8.8	6.2	6.2	5.7	5.7	3.0	2.8	294
Mothers	8.1	6.1	6.3	5.5	6.0	3.3	3.1	
Poles—								
Fathers	6.8	6.5	5.9	5.6	5.7	3.6	3.2	64
Mothers	7.1	5.3	5.6	4.4	5.2	3.2	2.7	
Hebrews—								
Fathers	9.3	5.5	6.2	5.3	5.7	3.1	3.3	618
Mothers	8.4	5.7	5.9	4.9	5.6	3.0	3.2	
Scotch—								
Fathers	10.7	6.1	5.4	5.0	5.9	1.8	3.4	37
Mothers	9.8	6.1	4.8	3.9	4.9	2.1	2.2	

TABLE 3

Coefficients of Variation

	LH	WH	WF	AVE.		LH	WH	WF	AVE.
Sicilians—					Bohemians—				
Fathers	3.1	3.5	3.8	3.5	Fathers	3.2	3.5	4.0	3.6
Mothers	3.2	3.5	3.6	3.4	Mothers	3.5	3.6	4.3	3.8
Italians—					Hebrews—				
Fathers	3.6	3.7	3.9	3.7	Fathers	3.3	3.4	4.1	3.6
Mothers	3.4	3.7	4.0	3.7	Mothers	3.3	3.3	4.2	3.6

Table 3, as expected, gives no evidence for real sex difference in relative variability. The racial averages also show little regular trend; but there is a consistent increase in variability from the larger to the smaller measurements, for the further elucidation of which we shall add in Table 4 the corresponding V's for stature and for the two indexes.

TABLE 4

Coefficients of Variation

	ST	CI	WFI		ST	CI	WFI
Sicilians—				Bohemians—			
Fathers	3.5	4.0	3.1	Fathers	3.7	3.6	3.1
Mothers	3.7	4.3	3.3	Mothers	3.9	3.9	3.6
Italians—				Hebrews—			
Fathers	3.3	5.0	3.5	Fathers	3.3	3.7	3.7
Mothers	3.6	3.1	3.2	Mothers	3.7	3.6	3.6

But Table 4 reveals no additional consistencies except a consistent sex difference in variability of stature in favor of the mothers.

The remarkable homogeneity of all the series deserves a word in passing; V's for measurements of toads were shown by Willoughby and Pomerat (20) to be about half again as large as those reported here for indices, and about three times as large for direct measurements; and V's of 15 to 30 are not rare in general biometrical work. The most plausible hypothesis for these small figures is the considerable endogamy and probable consequent homozygosis in most racial human groups. Coincident with this homogeneity, however, the occasional occurrence of an apparent mutant is striking; as illustration may be mentioned a Bohemian mother with a face width of 106 mm. in a population of 294 individuals having a mean of 140 mm., a standard deviation of 6 mm., and a total range (excluding the aberrant individual) of 30 (122-152) mm. Cases of this sort occur some four or five times in the present series of upwards of 9500 measurements on about 1700 individuals; they are probably not due to clerical error, partly because the original data were carefully checked before publication and partly because associated measurements have a tendency to vary, though not proportionately, with the aberrant measurement.

"RACIAL" INFLUENCES ON HOMOGAMY

The average of the coefficients presented in Table 5 gives a measure of the degree of homogamy characteristic of a national group, and the average deviation is a rough though adequate measure of the dispersion of the coefficients around this average. On this basis the seven groups fall into two divisions, one with an average homogamy of about .12 and the other of about half that amount or a little less; the groups with small populations fall in the latter division. The N given is the most characteristic size of the population.

TABLE 5

	r	AD	N
Sicilians	.11	.03	337
Central Italians	.12	.03	284
Hebrews	.12	.03	618
Hungarians-Slovaks	.04	.06	91
Bohemians	.05	.05	294
Poles	.05	.06	64
Scotch	.05	.13	37

Certain inferences are suggested by the figures of Table 5: (1) for many purposes "racial" differences in homogamy may be disregarded, although in mixtures where the component groups have averages considerably different (as in America) the coefficients can probably be expected to be, not an average of those for the components, but ones raised by a proportionately substantial amount, as in Pearl's (11) instance of the two species of *Paramecium* mating in the same bottle—provided there be factors present which lead to mating within the group. In the absence of any more likely explanation, it is suggested that Pearson and Lee's (14) figures, which average about .10 higher than our higher division, is due to this cause, since England is a conspicuous example of "race" mixture involving different averages. (2) The most obvious differentia between the divisions is that the higher division is Mediterranean (the fact that the Hebrews were born in East Europe is offset by their relative endogamy) and the lower Nordic and Slavic. It is possible that the histories of these groups may account for their very slightly different variabilities (Mediterranean average σ 5.42, Nordics-Slavs 5.35) and so in part for their differences in homogamy; but

at the same time we must recall that the small numbers, the high AD's, and the fact that all of the seven negative coefficients occur in the lower division makes reasoning about differences precarious—for it is quite possible that additional numbers would stabilize the figures, and impossible to say at what level they would stabilize them.

VARIATIONS IN HOMOGAMY WITH THE VARIABLES

A measure of the degree of homogamy appertaining to a given trait or variable may be obtained by computing the weighted average of the homogamy coefficients for that trait without respect to "racial" group; the average deviations of the individual coefficients from this measure may be used as a rough index of the representativeness of the former figures. Since about 1700 pairs of measurements contribute to each such weighted average, the comparison is statistically quite significant. The weighted averages and AD's are given in Table 6.

TABLE 6

	r_w	AD
Stature	.16[1]	.06
Face width (WF)	.15	.08
Head width (WH)	.10	.05
Cephalic index (WH/LH) ...	.08[2]	.04
Face width index (WF/WH)	.08	.06
Head length (LH)	.06	.08

[1] Cf. Schiller's (17) figures of .36 for height and .43 and .32 (before and after marriage) for weight.

[2] Cf. Boas' (1) figure of .15 for CI.

It will be observed that the coefficients fall into two groups, the higher at about .16 and the lower at half that amount. It is to be noted that the higher group comprises those measurements which are visually the most obvious, which suggests the hypothesis that they are somewhat selected sexually in the sense that the more desirable individuals may successfully choose mates most closely approaching the group standard (which they themselves most nearly approach), leaving the less desirable individuals to mate with those farther away from the standard, as they themselves are.

It is convenient to derive a single general measure of continental European homogamy from these weighted averages, since they may

themselves be averaged without distortion, and to express in terms of a corresponding AD (unweighted) the deviation of the individual measures of homogamy from it. This procedure yields

r	AD
.10	.06

and by virtue of the more than 9500 pairs of measurements entering into its determination this figure expresses with much stability the degree of assortative mating for a large section of the human race. In interpretation nothing more can be said at present than that it is substantially lower than earlier work has led us to anticipate, that it is comparable with the figures for other animals, particularly arthropods (Pomerat, 15, 16), and that its source and evolutionary significance are as yet essentially unknown but probably not negligible over long periods of time and for large populations.

HOMOGAMY CORRELATIONS IN AGE

Correlations previously reported in age may be grouped as (a) from unselected populations, and (b) from populations of parents or otherwise selected groups. In the former may be mentioned those of Lutz (10) on a series from the Chicago marriage license office and of Pearson and Heron (13) on the British census of 1901; both series are so large as to render the probable errors negligible. The coefficients are

Lutz	.764
Pearson-Heron ...	.925

An additional coefficient could be derived from the figures of Bossard (4) on a large Philadelphia series, but in view of the fact that the present paper is concerned primarily with somatic homogamy this has not been done.

Age correlations from populations of parents or other selected groups have been reported by Carter (5) and Schiller (17). These are based upon relatively small populations, viz., 108 pairs in the case of Carter and 46 in that of Schiller; the coefficients are

Carter	.75
Schiller	.69

Additional coefficients could probably be derived from the data of a number of other investigators who have been interested in age only incidentally, e.g., Willoughby (19), Goodenough (7), and Jersild (9).*

The present figures, although strictly comparable only with that of Carter among those mentioned, are almost exactly midway between those for the unselected populations of Lutz and Pearson-Heron. This suggests that the married population among European groups is more nearly identical with the parent population than is the case in America. The weighted average for the seven European groups is

$$r_a = .84 \ (N = 1700)$$

and the coefficients by racial groups given in Table 7 (with one exception, probably due to the shortness of the series) are close to the average, indicating that in this trait as in the others there is no reason to postulate true national differences.

TABLE 7

	r	N
Sicilians	.83	334
Central Italians	.82	283
Hungarians-Slovaks	.84	88
Bohemians	.83	288
Poles	.66	62
Hebrews	.89	608
Scotch	.83	37

MODIFICATION OF MEASUREMENTS WITH AGE

Only a limited sampling of age-measurement correlations were computed; these were for the most part selected so as to produce at least one such correlation from each racial group and at least one from each measurement, and in general those measurements and groups were favored which showed a direct homogamy of over .15, since those below that figure are frequently not certainly demonstrable (i.e., it is not worth while attempting to determine whether a given coefficient is due to the influence of age unless one is fairly certain that the said coeffi-

* The last has found (unpublished data) homogamy coefficients of .26 for ability to sing low notes and —.32 for ability to sing high notes (25 pairs of parents of young children).

cient is not illusory). The results appear to warrant three generalizations, though not to warrant them with positiveness; in considering the coefficients it should be remembered that several coefficients which are mutually corroboratory deserve more evidential weight than their individual size would warrant when taken alone. The first of these generalizations is that there is a slight tendency for stature to decrease with

TABLE 8

	r_{aa}	N
Central Italians—		
Fathers	—.09	269
Mothers	—.15	
Hungarians-Slovaks—		
Fathers	—.22	91
Mothers	—.06	
Scotch—		
Fathers	—.07	36
Mothers	—.26	

TABLE 9

	r_{ab}	N
Poles, head length—		
Fathers	.00	64
Mothers	.21	
Hebrews, head length—		
Fathers	.00	618
Mothers	—.02	
Sicilians, head width—		
Fathers	.07	337
Mothers	.00	
Central Italians, face width—		
Fathers	.10	284
Mothers	.14	
Bohemians, face width—		
Fathers	.16	294
Mothers	.20	
Hebrews, face width—		
Fathers	.06	476
Mothers	.11	

increasing age; while this is not a wholly unexpected finding, the evidence for it should be presented, and appears in Table 8.

The second generalization is that there is a similarly slight tendency for the head measurements to increase with increasing age, as shown in Table 9.

The third generalization, concerning the indexes of head form, given in Table 10, is that whereas the cephalic index remains practically constant throughout the life of the individual, the facial index tends to increase slightly, suggesting a differential rate of development as between the bones of the face and those of the parietal region. The selection of the populations was made in advance of information as to the size of the correlations, and depends only on the existence of an adequate population.

TABLE 10

	r_{al}	N
Sicilians (Ci)—		
Fathers	.06	337
Mothers	—.06	332
Hebrews (Wfi)—		
Fathers	.10	475
Mothers	.08	469

THE EFFECT OF AGE ON HOMOGAMY

Interest in homogamy revolves about two problems:

(1) To what is the observed degree of homogamy due?

(2) What are the consequences of the observed degree of homogamy?

The answer to the first, in the usual manner of scientific problems, can be found only by the technique of formulating reasonable hypotheses as to source and checking them against observed facts. The form of the present data permits the formulation and testing of one of these particular hypotheses, viz., that the cause of what homogamy there is is the common correlation of the measures with age, plus the fact that mates are of approximately the same ages. We have seen that while there is not a marked correlation of any measure with age, nevertheless a case might be made out for the generalization that stature decreases some-

what and the head measurements increase somewhat with increasing age. The technique of partial correlation will enable us to determine whether these slight variations are sufficient to "explain" the observed homogamy correlations; i. e., if holding constant the ages of wife and husband reduces the homogamy, we may suppose an influence of the age factor in producing the correlation; if not, such an influence is impossible. In applying this test, we need not partial out age from all possible correlations; from the random sampling of coefficients for which we have computed the correlation between age and measurement we may select that showing the largest such age-measurement correlation; if this is shown to be ineffective in producing the observed homogamy, then *a fortiori* smaller coefficients must also be ineffective. The selected coefficient is that (.16) between the face widths of the Bohemian fathers and mothers. It is based on an adequate population (294 pairs); the correlation between age and face width in the fathers is .16, and the corresponding figure for the mothers .20. The partial correlation we seek is

$$r_{ff.aa} = .13$$

which is reduced only slightly from the original coefficient. It therefore follows that our hypothesis is disproven, and that age has no appreciable effect upon the observed homogamy in this series. We have no further hypothesis which we may test; the source of the correlation is, as before, unknown.

THE QUALITATIVE VARIABLES

The investigation of homogamy in hair and eye color is unsatisfactory in this series for a number of reasons. For example, many of the parents have grayed hair, and this may introduce a selective factor; and in series such as the Sicilians the opportunity for choice is limited by the fact that with rare exceptions all Sicilians are dark; since practically all the members of this series have entries of either 1, 2, or 3 on the scale of about 18 effective units used, in which 1 is pure black, it is difficult to derive a meaningful measure of homogamy. For these reasons the Bohemians were selected as being a population of heterogeneous coloration, and the coefficients for hair and eye color were computed for them. The former, because of the graded series of notation used, could be secured by the product-moment method, and gave a rectilinear scatter (both distributions skewed toward the lighter end), with a coefficient of

.03 (208 couples). The coefficient of contingency was computed for the homogamy in eye color, and this turned out to be .67 ($N = 293$); the table is reproduced here as a matter of interest (Table 11).

TABLE 11

Homogamy in Eye Color

		FATHERS										
		Brown	L. Br.	Dk. Br.	Gr. Br.	Blue	L. Bl.	Gr. Bl.	Gray	Bl. Gr.	Dk. Bl.	Totals
MOTHERS	Brown	42	4	4	3	33	2	3	17	..	..	108
	L. Br.	5	3	1	..	3	..	2	1	..	..	15
	Dk. Br.	2	..	3	..	2	1	..	3	..	..	11
	Gr. Br.	..	1	1	6	1	1	..	..	..	..	10
	Blue	25	3	9	1	27	1	..	8	..	..	74
	L. Bl.	2	2	2	..	1	4	1	1	..	..	13
	Gr. Bl.	1	2	1	..	1	..	3	1	..	..	9
	Gray	18	2	3	..	13	2	..	9	..	2	49
	Bl. Gr.	..	..	..	..	1	2	..	..	..	..	3
	Dk. Bl.	..	..	..	..	..	..	..	..	..	1	1
	Totals	95	17	24	10	82	13	9	40	0	3	293

The value .67 may be compared with figures of .34, .14, and .21 (all coefficients of contingency) for hair color, secured by Harris (8), Williams (18), and Schiller (17) respectively; and with .26 and .42 (both contingency) for eye color, due to Pearson (12) and Schiller respectively. It is clear that either the populations or the methods employed are still quite unstable.

SELF-CORRELATION

Only one self-correlation was computed, since a colleague has expressed his intention of covering the subject more thoroughly than the scope of the present paper contemplates. It was that between stature and head length in the Hebrews, and yields coefficients as follows:

	r_{sh}	N
Fathers	.27	418
Mothers	.22	

These figures are fairly comparable with those found in the examination of the American white draft army (6):

	r
Leg length-waist circumference	.16
Chest circumference-bicristal diameter	.31
Stature-span	.79
Chest circumference-neck circumference	.51
Chest circumference-bicristal diameter	.31

The figures of Pearson and Lee (14) on stature vs. span are similar to the army figure:

	r
Fathers	.78
Mothers	.76
Sons	.80
Daughters	.83

It may be observed in passing that the standard deviations for our Hebrews vary (in both measurements) with the self-correlation; i. e., the fathers have larger variabilities in both stature and head length than do the mothers, and they also have the higher self-correlation. The same is true for the coefficients of variation in Pearson and Lee's data. These facts tend to corroborate the suggestion of Willoughby and Pomerat (20) based on their work with toads, that variability and self-correlation are closely associated, possibly to the extent that all sex differences in self-correlations are due to corresponding differences in variability.

SUMMARY AND TABLE OF CORRELATIONS

The principal findings may be summarized as follows:

(1) There is a marked male superiority in age and size in all national groups, but slight sex differences in the indices.

(2) The males are slightly superior in absolute variability, but this is probably related to their larger size; all the series are remarkably homogeneous.

(3) The homogamy coefficients fall into two groups; one, averaging about .12, includes the Sicilians, Central Italians, and Hebrews; the other, averaging about .05, includes the Hungarians-Slovaks, Bohemians, Poles, and Scotch. With respect to the variables, the coefficient for stature is highest (.16); the index coefficients average half that

figure, and the head measurements yield average coefficients of .15, .10, and .06. A total weighted average of all coefficients yields a value of .10, and the very large number of observations included in this figure makes it probably the most stable yet secured for any species.

(4) Homogamy coefficients in age average about .84, and show little variation with racial groups.

(5) There is a slight tendency for stature to decrease with age, and for the head measurements to increase; the cephalic index remains approximately constant, but the facial index increases slightly. None of these changes are adequate to explain any considerable part of the homogamy in measurements.

(6) Among the Bohemians, a population selected for heterogeneity in these variables, there is practically zero homogamy in hair color, but a coefficient of contingency of about .67 in eye color.

TABLE 12

	AGE	ST	WFI	LH	CI	WH	WF	M
Sicilians—								
N	334	337	128	337	336	337	336	
r	.83	.11	.13	.04	.13	.16	.12	.11
Central Italians—								
N	283	269	284	271	273	284	284	
r	.82	.17	.05	.10	.11	.12	.17	.12
Hungarians-Slovaks—								
N	88	91	91	91	91	91	91	
r	.84	.19	.08	.03	—.01	.05	—.08	.04
Bohemians—								
N	288	294	294	293	225	296	294	
r	.83	.10	.06	—.06	.02	.05	.16	.05
Poles—								
N	62	64	64	64	64	64	64	
r	.66	.08	—.06	.17	.07	—.02	.06	.05
Hebrews—								
N	608	418	477	618	619	618	476	
r	.89	.12	.14	.12	.08	.09	.22	.12
Scotch—								
N	37	36	37	37	36	37	37	
r	.83	.32	—.07	—.14	.01	.17	.01	.05
M	.84	.16	.08	.06	.08	.10	.15	

(7) Self-correlation of about .25 was found in the Hebrews between stature and head length.

The homogamy coefficients and population sizes are given in Table 12.

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A COMPARATIVE STUDY OF THE PHYSICAL STATUS OF EAST TENNESSEE MOUNTAIN CHILDREN

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Mountain people of the Southern Appalachians have attracted the attention of students in many fields. Both subjective and objective investigators have invaded the Highlands in an attempt to discover some explanation and solution to the peculiar problems of these isolated people. Fiction has pictured the mountaineer as a tall, sturdy individual with fair hair and blue eyes, continuously participating in ancestral feuds, and extremely backward in the sense that during the past two hundred years he has failed to improve his rugged environment as rapidly as his kinsfolk who settled outside the mountains. As one gains an intimate knowledge of these people it becomes difficult to accept this subjective characterization without question. To give a true picture of the abilities, personalities, and achievements of these people, there is a great need for more objective and scientific studies. Toward this end we are presenting the results of an investigation of the physical status of mountain children. It is hoped that this method of study may encourage further scientific research in this field and lead to new interpretations of the Southern Mountaineer.

Several investigations have attempted to show the climatic and geographic influences on height and weight. Adsersen(1) found that geographic location seemed to affect the seasonal variations in the weight and length of the new born studied in Danish and German lying-in hospitals. An anonymous study(3) published in the *Bulletin Médical* (1903) reports that mountain air affects weight improvement. There are so many factors which might affect growth in addition to mountain air that it seems highly speculative for this investigator to draw any definite conclusions. Baxter(6) studied the size of adult Americans in different states of the union and in different parts of the same state. He seems to find that climate and location influence growth. Gardiner(12), in a study of climate on the development of 1,000 school children of Colorado Springs, indicates that

Colorado children are superior in height, weight, and other measures when compared with children in St. Louis and Chicago, but he does not consider the results as conclusive. Spier(16) made a comparison of 521 Japanese children born in Southern Japan with 922 Japanese children born in Seattle, Washington. He finds the American born children are taller, with longer and wider heads and faces. The Seattle children are taller than Japanese children born in California. Children born before six years of residence in the United States are smaller than children born after six years residence. However, after studying the reliability of the differences between the groups, there appears a significant difference in height for the boys in only three out of the eight age groups studied and in only two out of the eight age groups for the girls. There seems to be a significant difference in the majority of other measures. Rand(15) has discussed the influence of growth and development on the young child and cites a number of studies indicating the influence of heredity and environment. The studies which he cites show that height could be materially influenced by environmental factors. Children of Russian Jews who have migrated to America seem to be above the children of the old country. The size of the Japanese is greatly influenced by their food intake during the period of growth. He believes that the present generation of American children is taller and heavier than the parents. Other studies indicate that children of other European countries seem to grow taller and heavier after they come to live in America. If these conditions exist, some of the early standards for physical growth may be too low to represent the growth of normal American children today.

In studying the problem of the influence of rural and urban life on development, Zhbankoff(19) measured 1,051 boys, ages 7-14, in rural schools two or three times at intervals of one year. He compares height and chest with other investigations and concludes that "the assertion that rural schools have a bad effect on the children's health has no basis." Allaria(2) studied the height, weight and lung capacity of 652 girls employed in urban industries, 420 girls employed in rural cotton factories, and 158 girls of well-to-do families. The investigator reports that the well-to-do girls were superior in all measures. He attributes this to their more favorable social and domestic environment. Aron and Lubinsky(4) measured the height and weight of 223 school boys in the village of Dentsch-Rosselivitz, 202 from private schools in Breslau and 261 from city public schools. All were of the same race and included ages 7-13. Private school children showed the greatest height and weight and country children only a little above that of city public school children. When the author compared the groups according to Livi's *index ponderalis* $\left(100\sqrt{\frac{ht}{wt}}\right)$ the country children showed the best results and the private school pupils the worst. The authors believe that the work of the country children seems to retard height and to develop the muscles, and that the superior height of the city children is but a temporary phenomenon,—other children later equal them.

The influence of diet and proper care on growth has been studied by a number of investigators. Bendix(7) states that infants seem to thrive on the most unscientific diet, and in many cases where only the bare necessities of life are available. He describes eleven cases of twins who differed little in weight at birth, but with practically the same diet and treatment showed quite a divergence in general development with an increase in age. Chose(8) studied the height and weight of

rachitic children from the ages of five and one-half to seven and one-half, in the public schools of Munich. He found that the rachitic children showed no inferiority in height and very little in weight. Even this inferiority in weight was probably due not to rickets, but to other ill effects of the same factors that caused the rickets. Davenport(10) has made an intensive study of the problem of growth and believes that the specific growth factor will eventually work itself out in spite of unfavorable environmental factors which apparently might retard it. Temporary lack of food might retard growth, but has little or no effect on the end point of growth which is materially set by heredity. He also believes that the tallness of people in Kentucky and the Carolinas is due to Scotch ancestry rather than to environmental factors. Stoke(17) studied the physical growth of children in relation to their occupational groupings. He maintains that malnutrition has little effect on the development of height. He believes height is controlled mostly by heredity, and that weight is the most susceptible to environment. Franzen(11) studied the effect of nutrition on weight and height. He concludes that we must discard weight in any form as a diagnostic measure because of the huge rôle played by skeletal differences in the determination of weight. He seems to think that it is better to use a combination of different physical traits, and maintains the weight-height ratio measures mainly developmental factors not associated with nutrition.

Several of the investigations already mentioned show the influence of social and economic status on growth. Gray(13) also has studied these influences among private school children in Illinois, New York City, Massachusetts, California and Pennsylvania. He compared ten different measures of these children with Baldwin's norms and with other groups. He found that the private school children were superior in a number of traits. This study confirms a number of other investigations indicating that private school children are superior in physical development. Young(18) made a study of 404 girls and 201 boys from the education school connected with the University of Chicago. She measured height and weight, and studied the effect of tonsils and adenoids on scholastic achievement. In comparing her results with other groups, she found that children of the well-to-do classes were taller and heavier than the regular public school children of the country.

No attempt has been made to survey all the literature on physical growth. Brief comments have been made only upon some of the investigations which might have a direct bearing on the physical status of mountain children. A comprehensive survey on physical growth is found in Baldwin's studies(5), and in bulletins on physical growth published by the U. S. Bureau of Education. There is a great need for investigators to include more comprehensive tables, to give adequate reliability measures, and to standardize the technique of anthropometric measures.

THE DATA

During the spring of 1932 we measured the height and weight of 1475 mountain children from ages six through seventeen. It is generally accepted that these two measures give as fair an index of physical status as any other two traits, although they may not be a true index of the nutritional condition of children. The measures were made without shoes and coats, and every precaution was taken to make them as accurate as possible. The reliability of the technique of measurements was figured for two hundred cases, and was found to be:

$$\text{height, } r = .99 \pm .001, \text{ weight, } r = .87 \pm .036.$$

Fairbank's portable scales were used for obtaining the weight, and a separate stadiometer for height. The children included in this study all live under the direct influence of isolated mountains of East Tennessee and are typical of children in public mountain schools. The writer wishes to acknowledge the hearty coöperation of Superintendents K. P. Banks and H. P. Gentry, and of the teachers who have given their support to the investigation.

No attempt was made to classify the children according to race. It is generally accepted that these people are a fairly pure North European race, from English, German, Scotch and Irish ancestry. The economic status of the people is low, and no attention is given to a balanced diet. Practically all the parents follow either agriculture or lumbering. The findings in this investigation should give a representative picture of what might be found in other Southern mountains.

One of the most difficult problems encountered in a study of physical growth is the lack of comprehensive tables in previous investigations. Most of the studies do not include sufficient reliability measures to enable one to make accurate and scientific comparisons. We have endeavored in this discussion to give full data so that other investigators may make further comparisons. Table 1 shows the number of cases for each age from six through seventeen. The central tendencies are shown by the medians and averages, their reliability is indicated by the probable errors and the spread of the groups is shown by the mean deviations. In making several comparisons, it has been unfortunate that we could not determine the reliability. This could have been done had previous investigators included such material in their reports. Any comparison made without the proper reliability measures is greatly limited and in many cases practically meaningless.

TABLE 1

Height and Weight of East Tennessee Mountain Children

	AGES	6	7	8	9	10	11	12	13	14	15	16	17
Boys Height (cm.)	N	28	65	64	87	83	91	80	77	66	49	28	21
	Mean	116.76	119.36	124.49	127.97	137.10	139.17	144.42	151.46	153.02	162.03	164.80	171.68
	Deviation of Mean	4.39	4.95	4.95	6.30	5.51	5.51	6.40	6.96	7.90	8.08	5.28	4.57
	Median	114.30	119.38	126.37	129.31	134.21	139.12	143.76	148.46	151.13	164.47	163.83	171.78
	P. E. Median	.890	.595	.603	.539	.638	.549	.905	.802	1.075	1.302	.746	1.142
	Range	107.95	106.68	111.76	106.68	124.46	93.98	127.00	132.08	129.54	142.24	149.86	158.75
		128.27	132.08	148.59	158.76	165.10	163.83	175.26	173.99	217.17	181.61	177.80	189.23
Girls Height (cm.)	N	20	48	77	78	107	91	83	79	60	56	21	16
	Mean	112.93	118.64	124.75	129.34	136.27	139.42	145.48	152.35	155.17	158.72	158.47	158.93
	Deviation of Mean	4.72	4.29	4.60	5.41	6.38	5.94	6.76	5.87	5.36	6.48	4.01	5.61
	Median	111.76	116.84	125.81	131.01	137.36	138.89	146.58	152.45	156.46	158.55	158.45	158.75
	P. E. Median	1.157	.646	.394	.620	.611	.629	.708	.547	.798	.873	.635	1.650
	Range	100.33	107.95	111.76	113.03	116.84	124.46	129.54	125.73	134.62	135.89	147.32	137.16
		119.38	128.27	140.97	147.32	161.29	160.02	171.45	167.64	166.37	171.45	167.64	165.10
Boys Weight (kg.)	N	28	65	64	87	83	91	80	77	66	49	28	21
	Mean	22.32	23.45	25.58	27.31	30.93	33.47	36.70	39.87	44.09	51.53	54.43	60.65
	Deviation of Mean	2.36	2.36	2.36	2.90	2.99	3.17	4.68	5.04	6.89	7.94	6.62	5.35
	Median	22.23	23.13	24.95	27.72	30.35	33.25	36.17	38.93	41.73	51.82	53.52	61.57
	P. E. Median	.505	.337	.319	.320	.347	.367	.522	.722	.775	1.514	1.625	1.243
	Range	18.14	17.24	19.50	20.87	21.77	24.95	23.59	28.58	32.20	34.02	37.19	48.53
		29.94	31.30	32.20	42.18	44.45	44.91	53.98	61.23	67.58	74.39	69.40	70.76
Girls Weight (kg.)	N	20	48	77	78	107	91	83	79	60	56	21	16
	Mean	19.19	21.77	24.63	26.85	30.08	33.47	35.97	44.50	47.22	48.76	48.76	50.80
	Deviation of Mean	1.76	2.03	2.41	2.86	4.04	4.17	4.72	6.17	5.71	4.90	3.45	7.21
	Median	19.05	22.23	24.66	27.03	30.43	32.85	35.27	42.87	45.95	48.08	47.67	53.75
	P. E Median	.531	.292	.429	.309	.443	.462	.524	.744	.805	.815	.806	1.418
	Range	15.42	15.42	18.60	19.50	19.50	25.40	19.50	28.12	31.75	30.84	39.01	43.09
		24.04	27.67	31.75	47.63	41.73	52.62	58.97	72.12	61.69	64.86	58.97	66.22

Weight	P. E Median	.531	.292	.429	.309	.443	.462	.524	.744	.805	.813	
	Range	15.42–24.04	15.42–27.67	18.60–31.75	19.50–47.63	19.50–41.73	25.40–52.62	19.50–58.97	28.12–72.12	31.75–61.69	30.84–64.86	39.01–58.97	43.09–66.22

TABLE 2

Comparison of Height and Weight of Mountain Children with Baldwin's Final Norms for American Children

AGES	7	8	9	10	11	12	13	14	15	16	17	AVER.
Height Boys—												
Baldwin	121.56	125.70	130.72	135.47	140.27	144.81	150.96	156.99	163.14	169.24	172.87	
Mountain Children	119.36	124.49	127.97	137.10	139.17	144.42	151.46	153.02	162.03	164.80	171.68	
Difference	2.20	1.21	2.75	—1.63	1.10	0.39	—0.50	3.97	1.11	4.44	1.19	1.47
Height Girls—												
Baldwin	120.04	124.16	129.13	135.48	140.57	145.58	151.72	156.01	159.71	161.55	161.75	
Mountain Children	118.64	124.75	129.34	136.27	139.42	145.48	152.35	155.17	158.72	158.47	158.93	
Difference	1.40	—0.59	—0.21	—0.79	1.15	0.10	—0.63	0.84	0.99	3.08	2.82	0.74
Weight Boys—												
Baldwin	22.87	24.68	27.49	29.90	32.62	35.51	40.05	44.50	49.86	54.96	59.13	
Mountain Children	23.45	25.58	27.31	30.93	33.47	36.70	39.87	44.09	51.53	54.43	60.65	
Difference	—0.58	—0.90	0.18	—1.03	—0.85	—1.19	0.18	0.41	—1.67	—0.53	—1.52	—0.59
Weight Girls—												
Baldwin	22.76	24.41	27.75	31.41	34.36	37.97	43.68	48.10	53.40	55.38	55.70	
Mountain Children	21.77	24.63	26.85	30.08	33.47	35.97	44.50	47.22	48.76	48.76	50.80	
Difference	0.99	—0.22	0.90	1.33	0.89	2.00	—0.82	0.88	4.64	6.62	4.90	2.01

COMPARISONS WITH OTHER GROUPS OF CHILDREN

Table 2 shows a comparison of the mountain children with Baldwin's final norms for American children.[1] Baldwin's boys seem to be above the mountain children in height in the majority of ages, and the girls appear taller than the mountain children in about one-half of the cases. For weight the mountain boys are above Baldwin's norms and the girls are below in the majority of ages. The average difference between the groups appears in favor of Baldwin's norms.

When we study the mean deviations of the groups as shown in Table 3, these differences become questionable as to statistical significance. There seems to be a greater difference in the upper ages. This might be partly explained by the small number of cases at these age levels.

The mountain boys and girls are above the Boston laboring class as measured by Bowditch[2] in practically all measures in height and weight

TABLE 3

Comparison of Mean Deviations of Mountain Children and Baldwin's Final Norms

AGES	6	7	8	9	10	11	12	13	14	15	16	17
Height Boys—												
Baldwin	0.0	6.00	5.17	6.09	6.02	6.08	5.79	6.34	7.03	6.95	6.59	5.72
Mt. Children...	4.39	4.95	4.95	6.30	5.51	5.51	6.40	6.96	7.90	8.08	5.28	4.57
Height Girls—												
Baldwin	0.0	4.21	4.02	4.37	5.02	5.75	6.13	6.36	6.25	5.84	5.87	5.67
Mt. Children...	4.72	4.29	4.60	5.41	6.38	5.94	6.76	5.87	5.36	6.48	4.01	5.61
Weight Boys—												
Baldwin	0.0	2.80	2.64	3.38	3.82	4.47	4.44	5.25	6.39	6.40	5.90	5.38
Mt. Children...	2.36	2.36	2.36	2.90	2.99	3.17	4.68	5.04	6.89	7.94	6.62	5.35
Weight Girls—												
Baldwin	0.0	2.43	2.65	3.85	4.55	5.10	6.07	6.82	6.58	6.44	6.24	6.65
Mt. Children...	1.76	2.03	2.41	2.86	4.04	4.17	4.72	6.17	5.71	4.90	3.45	7.21

[1] See Baldwin, B. T. Physical Growth of Children from Birth to Maturity, p. 153.

[2] See Baldwin, B. T. *ibid.*, p. 263. Also the 8th annual report of the Massachusetts State Board of Health, 1877.

as shown in Table 4. There seems to be a greater difference in height than in weight, although we are not able to say whether the difference is significant without reliability measures.

The mountain children are above the Boston non-laboring class in practically all ages. See Table 5. Again we are not able to determine the statistical difference between the groups without reliability measures,

TABLE 4

Comparison of Mountain Children with Boston Laboring Class Measured by Bowditch

AGES	8	9	10	11	12	13	14	15	Aver.
Height Boys—									
Laboring Class ...	121.2	126.4	131.0	135.1	139.5	144.5	150.7	...	
Mt. Children	124.5	130.0	137.1	139.2	144.4	151.5	153.0	...	
Difference	—3.3	—3.6	—6.1	—4.1	—4.9	—7.0	—2.3	...	—4.4
Height Girls—									
Laboring Class ...	120.6	125.2	130.3	135.7	141.5	147.4	152.1	...	
Mt. Children	124.8	129.3	136.3	139.4	145.5	152.4	155.2	...	
Difference	—4.2	—4.1	—6.0	—3.7	—4.0	—5.0	—3.1	...	—4.3
Weight Boys—									
Laboring Class ...	24.3	26.9	29.6	31.6	34.4	37.8	42.5	47.6	
Mt. Children	25.6	27.3	30.9	33.5	36.7	39.9	44.1	51.5	
Difference	—1.3	— .4	—1.3	—1.9	—2.3	—2.1	—1.6	—3.9	—1.9
Weight Girls—									
Laboring Class ...	25.5	25.7	28.1	30.8	35.2	39.7	44.4	47.7	
Mt. Children	24.6	26.9	30.1	33.5	36.0	44.5	47.2	48.8	
Difference	0.9	—1.2	—2.0	—2.7	—0.8	—4.8	—2.8	—1.1	—1.8

but the mountain children appear superior when we study the averages and the total average of the differences. It has been pointed out by Rand(15) that American children of the present generation are taller and heavier than their parents were at the same ages. Since Bowditch made his study in the 1870's, the standards he found might be low for the present generation. Another weakness of this comparison may be attributed to the fact that Bowditch did not classify his cases according to race. This might materially affect the results.

TABLE 5

Comparison of Mountain Children with Boston Non-Laboring Class Measured by Bowditch

AGES	8	9	10	11	12	13	14	15	Aver.
Height Boys—									
Non-Laboring	122.2	127.1	132.5	136.8	142.1	147.7	153.8	...	
Mt. Children	124.5	130.0	137.1	139.2	144.4	151.5	153.0	...	
Difference	—2.3	—2.9	—4.6	—2.4	—2.3	—3.8	0.8	...	—2.5
Height Girls—									
Non-Laboring	121.8	127.5	131.3	136.4	142.7	149.1	153.2	...	
Mt. Children	124.8	129.3	136.3	139.4	145.5	152.4	155.2	...	
Difference	—3.0	—1.8	—5.0	—3.0	—2.8	—3.3	—2.0	...	—3.6
Weight Boys—									
Non-Laboring	24.8	27.2	30.1	32.6	36.5	40.2	43.8	49.3	
Mt. Children	25.6	27.3	30.9	33.5	36.7	39.9	44.1	51.5	
Difference	—0.8	—0.1	—0.8	—0.9	—0.2	0.3	—0.3	—2.2	—0.62
Weight Girls—									
Non-Laboring	23.9	26.7	28.9	32.0	36.4	41.4	45.1	48.8	
Mt. Children	24.6	26.9	30.1	33.5	36.0	44.5	47.2	48.8	
Difference	—0.7	—0.2	—1.2	—1.5	0.4	—3.1	—2.1	0.0	—1.05

Another comparison was made between mountain children and the well-to-do class in Chicago as measured by Baldwin.[3] Table 6 shows that the well-to-do class is superior in height in the majority of cases, but the differences are small. The mountain boys seem to be above in weight while the girls are probably below, but the differences are so small it would be questionable to draw any conclusion without reliability measures. There seems to be no real difference between the well-to-do class in Chicago and the mountain children.

Another comparison was made between the mountain children and an unselected group in Oakland, California, measured by Robertson.[4] The California children seem to be taller for practically all ages, but there seems to be very little difference in weight as shown in Table 7. As to the cause, or the significance of the differences, we are not able to say.

[3] *Loc. cit.*

[4] See Baldwin, *ibid.*, pp. 265 and 284.

TABLE 6

Comparison of Mountain Children with Children of the Well-to-do Class in Chicago Measured by Baldwin

AGES	6	7	8	9	10	11	12	13	14	15	16	17	AVER.
Height Boys—													
Well-to-do Class	116.1	120.7	127.8	131.1	135.9	138.9	145.0	149.9	154.7	163.8	166.9	168.9	
Mountain Children	116.8	119.4	124.5	128.0	137.1	139.2	144.4	151.5	153.0	162.0	164.8	171.7	
Difference	—0.7	1.3	3.3	3.1	—1.2	—0.3	0.6	—1.6	1.7	1.8	2.1	—2.8	0.61
Height Girls—													
Well-to-do Class	114.6	120.9	125.0	130.8	134.6	140.0	145.8	152.9	157.0	159.0	159.8	159.8	
Mountain Children	112.9	118.6	124.8	129.3	136.3	139.4	145.5	152.4	155.2	158.7	158.5	158.9	
Difference	1.7	2.3	0.2	1.5	—1.7	0.6	0.3	0.5	1.8	0.3	1.3	0.9	0.81
Weight Boys—													
Well-to-do Class	21.3	22.5	25.9	26.6	30.5	32.3	34.8	39.0	43.6	48.8	50.8	56.6	
Mountain Children	22.3	23.5	25.6	27.3	30.9	33.5	36.7	39.9	44.1	51.5	54.4	60.7	
Difference	—1.0	—1.0	0.3	—0.7	—0.4	—1.2	—1.9	—0.9	—0.5	—2.7	—3.6	—4.1	—1.47
Weight Girls—													
Well-to-do Class	19.8	21.9	23.3	26.4	29.7	30.3	34.2	43.0	46.5	50.8	49.4	51.4	
Mountain Children	19.2	21.8	24.6	26.9	30.1	33.5	36.0	44.5	47.2	48.8	48.8	50.8	
Difference	0.6	0.1	—1.3	—0.5	—0.4	—3.2	—1.8	—1.5	—0.7	2.0	0.6	0.6	—0.46

TABLE 7

Comparison of Mountain Children with California Children Measured by Robertson

AGES	6	7	8	9	10	11	12	13	14	AVER.
Height Boys—										
California	117.1	121.0	127.8	132.6	135.9	142.2	151.6	151.4	156.7	
Mountain Children	116.8	119.4	124.5	128.0	137.1	139.2	144.4	151.5	153.0	
Difference	0.3	1.6	3.3	4.6	—1.2	3.0	7.2	—0.1	3.7	2.8
Height Girls—										
California	115.1	121.2	126.5	130.6	137.7	141.0	147.3	155.2	158.5	
Mountain Children	112.9	118.6	124.8	129.3	136.3	139.4	145.5	152.4	155.2	
Difference	2.2	2.6	1.7	1.3	1.4	1.6	1.8	2.8	3.3	2.1
Weight Boys—										
California	20.9	23.0	25.1	29.0	30.4	34.4	36.9	42.0	47.0	
Mountain Children	22.3	23.5	25.6	27.3	30.9	33.5	36.7	39.9	44.1	
Difference	—1.4	—0.5	—0.5	1.7	—0.5	0.9	0.2	2.1	2.9	0.54
Weight Girls—										
California	20.1	22.4	24.3	27.1	30.0	34.1	36.6	44.1	47.9	
Mountain Children	19.2	21.8	24.6	26.9	30.1	33.5	36.0	44.5	47.2	
Difference	0.9	0.6	—0.3	0.2	—0.1	0.6	0.6	—0.4	0.7	0.31

Clark(9) and others measured the height and weight of 7,132 boys and 7,203 girls in Maryland, Virginia, North Carolina, and South Carolina. They measured the children from age six through sixteen with clothes and shoes, and compared their findings with Baldwin's norms. The findings in this study might be used as typical for southern children. This study shows that southern children were below the standards, and the author attributes the differences to geographical conditions.

We have compared the mountain children with these southern norms as shown in Table 8. The mountain children are above in practically all measures and for all ages except at age six. There seems to be a real difference in some of the ages, but as to the significance we are not able to say for lack of reliability measures in the southern norms. The difference seems certainly to be in favor of the mountain children and this difference would be still greater if the southern children had been measured without shoes. We are fairly safe in saying that the mountain children seem to be above the southern children in height and weight.

Another comparison is made between mountain children and the norms for North European children compiled from the Harvard Growth Study by Latshaw(14). This is one of the most recent studies, and since there are adequate reliability measures and full statistical data for accurate comparisons it is probably the most scientific comparison we have been able to make.

Table 9 shows that the North European children are superior in height to the mountain children in the majority of ages, but after we study the reliability of the differences there are only four ages where the differences are statistically significant, or where the difference is four times the P. E. There is a real difference in height at the age of fourteen for boys and at the ages of seven, eleven, and thirteen for the girls. The North European children are heavier than the mountain children in the majority of ages, but there is a reliable difference only at age fourteen for the boys and at twelve and sixteen for the girls. The Harvard Growth Study Norms seem to be higher than other standards for the country. This may be due to the increased stature of the children, to the classification of the children according to race, or to some other factor which we are not able to explain from the present data.

TABLE 8

Comparison of Mountain Children with Southern Children Measured by Clark

AGES	6	7	8	9	10	11	12	13	14	15	16	AVER.
Height Boys—												
Southern Children	115.3	118.9	124.0	128.8	133.6	137.9	142.8	147.3	153.2	159.8	164.1	
Mountain Children	114.3	119.4	126.4	129.3	134.2	139.1	143.8	148.5	151.1	164.5	163.8	
Difference	1.0	—0.5	—2.4	—0.5	—0.6	—1.2	—1.0	—1.2	2.1	—4.7	0.3	—.79
Height Girls—												
Southern Children	113.8	118.4	122.9	128.3	133.4	138.4	144.8	150.6	155.2	158.8	160.8	
Mountain Children	111.8	116.8	125.8	131.0	137.4	138.9	146.6	152.5	156.5	158.6	158.6	
Difference	2.0	1.6	—2.9	—2.7	—4.0	—0.5	—1.8	—1.9	—1.3	0.2	2.2	—.83
Weight Boys—												
Southern Children	26.6	22.9	24.7	27.0	29.6	32.3	35.4	38.6	43.3	49.2	52.9	
Mountain Children	22.2	23.1	25.0	27.7	30.4	33.3	36.2	38.9	41.7	51.8	53.5	
Difference	4.4	—0.2	—0.3	—0.7	—0.8	—1.0	—0.8	—0.3	1.6	—2.6	—0.6	—.12
Weight Girls—												
Southern Children	20.6	21.9	23.8	26.3	29.0	31.9	36.2	40.7	45.1	48.8	51.5	
Mountain Children	19.1	22.2	24.7	27.0	30.4	32.9	35.3	42.9	46.0	48.1	47.7	
Difference	1.5	—0.3	—0.9	—0.7	—1.4	—1.0	0.9	—2.2	—0.9	0.7	3.8	.05

TABLE 9

Comparison of Mountain Children with North European Children

TABLE 9

Comparison of Mountain Children with North European Children

AGES	6	7	8	9	10	11	12	13	14	15	16
Height Boys Med.—											
North European	115.6	121.0	126.5	130.9	135.3	140.9	147.7	152.2	159.9	165.3	166.7
Mountain Children	114.3	119.4	126.4	129.3	134.2	139.1	143.8	148.5	151.1	164.5	163.8
Difference	1.3	1.6	.1	1.6	1.1	1.8	3.9	3.7	8.8	.8	2.9
D. ÷ P.E. (diff.)	1.55	2.58	.16	2.65	1.37	2.38	3.50	3.80	6.10	.53	2.40
Chances in 100	85	95	54	96	82	94	99	99	100	63	95
Height Girls Med.—											
North European	114.8	119.8	125.4	130.5	135.9	144.5	149.5	155.2	158.0	158.3	160.2
Mountain Children	111.8	116.8	125.8	131.0	137.4	138.9	146.6	152.5	156.5	158.6	158.6
Difference	3.0	3.0	—.4	—.5	—1.5	5.6	2.9	2.7	1.5	—.3	1.6
D. ÷ P.E. (diff.)	2.88	4.38	.90	.73	1.73	7.08	3.67	4.02	1.55	.31	1.89
Chances in 100	97	100	73	68	87	100	99	100	85	58	89
Weight Boys Med.—											
North European	21.3	23.5	26.0	27.9	30.4	33.1	39.2	42.3	48.6	53.8	55.7
Mountain Children	22.2	23.1	25.0	27.7	30.4	33.3	36.2	38.9	41.7	51.8	53.5
Difference	—.9	.4	1.0	.2	0.0	—.2	3.0	3.4	6.9	2.0	2.2
D. ÷ P.E. (diff.)	1.75	1.14	2.93	.50	0.0	.36	3.77	3.89	7.30	1.48	1.19
Chances in 100	88	77	97	63	50	59	99	99	100	84	78
Weight Girls Med.—											
North European	20.5	22.5	25.3	27.5	29.6	34.1	39.6	44.4	46.0	49.0	52.6
Mountain Children	19.1	22.2	24.7	27.0	30.4	32.9	35.3	42.9	46.0	48.1	47.7
Difference	1.4	.3	.6	.5	—.8	1.2	4.3	1.5	0.0	.9	4.9
D. ÷ P.E. (diff.)	2.58	.98	1.32	1.34	1.33	1.80	4.55	1.78	0.0	.93	4.75
Chances in 100	95	74	81	81	81	89	100	88	50	73	100

SUMMARY AND CONCLUSIONS

1. The lack of standardization in anthropological measures and the failure of previous investigators to include sufficient statistical data in their studies greatly handicap a comparative study of physical growth.

2. Mountain boys appear below Baldwin's norms in height and above in weight. Mountain girls appear below Baldwin's norms in height for about half the ages and below in weight for a majority of the ages. These differences become questionable when the mean deviations of the groups are compared.

3. Mountain children are above the Boston laboring and non-laboring classes in height and weight for practically all ages, but we are not able to give the statistical significance of these differences.

4. Mountain children compare favorably with the well-to-do classes in Chicago in height and weight.

5. California children seem to be superior to mountain children in height but show practically no difference in weight.

6. Mountain children appear taller and heavier than children of Maryland, Virginia, North and South Carolina for practically all ages studied.

7. North European children from the Harvard Growth Study seem to be above the mountain children in height and weight for the majority of age levels, but in the majority of ages the differences are not statistically significant.

8. We have attempted to compare the physical status of 1475 mountain children as measured by height and weight with seven investigations in various parts of the country.

9. Six of the comparisons had to be made without adequate reliability measures. Of these six comparisons for height the mountain children fall above in four and with no difference in two; for weight the mountain children are above in three and with no difference in three.

10. In the comparison made with adequate reliability measures, the mountain children seem to be below in both height and weight for the majority of ages, but in most of the age levels the differences are not statistically significant.

11. This investigation seems to indicate that mountain children compare favorably in height and weight with unselected groups in different parts of the country.

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RECENT LITERATURE

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